

EXHIBIT 12

(12) **United States Patent
Breed**

(10) **Patent No.: US 6,850,824 B2**
(45) **Date of Patent: Feb. 1, 2005**

- (54) **METHOD AND APPARATUS FOR
CONTROLLING A VEHICULAR
COMPONENT**
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Morris County, NJ (US)
- (73) Assignee: **Automotive Technologies
International, Inc.**, Denville, NJ (US)
- (*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.

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Primary Examiner—Yonel Beaulieu
(74) *Attorney, Agent, or Firm*—Brian Roffe

(57) ABSTRACT

Control system and method for controlling an occupant restraint system in which a plurality of electronic sensors are mounted at different locations on the vehicle, each sensor providing a measurement related to a state thereof or a measurement related to a state of the mounting location. A processor is coupled to the sensors and diagnoses the state of the vehicle based on the measurements of the sensors. The processor controls the occupant restraint system based at least in part on the diagnosed state of the vehicle in an attempt to minimize injury to an occupant.

31 Claims, 39 Drawing Sheets

(21) Appl. No.: **10/613,453**

(22) Filed: **Jul. 3, 2003**

(65) **Prior Publication Data**

US 2004/0039509 A1 Feb. 26, 2004

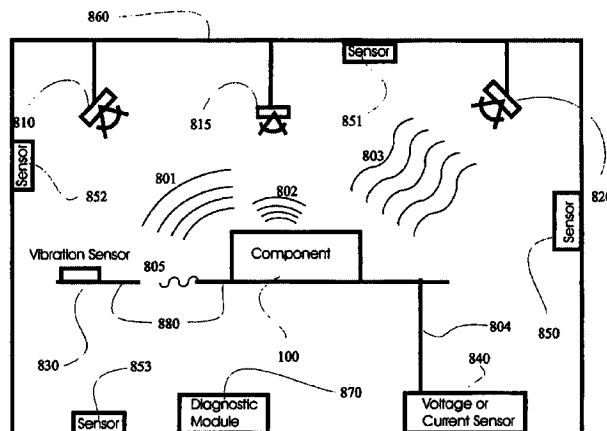
Related U.S. Application Data

- (63) Continuation of application No. 10/188,673, filed on Jul. 3, 2002, now Pat. No. 6,738,697, which is a continuation-in-part of application No. 10/174,709, filed on Jun. 19, 2002, now Pat. No. 6,735,506, and a continuation-in-part of application No. 09/753,186, filed on Jan. 2, 2001, now Pat. No. 6,484,080, which is a continuation-in-part of application No. 09/137,918, filed on Aug. 20, 1998, now Pat. No. 6,175,787, which is a continuation-in-part of application No. 08/476,077, filed on Jun. 7, 1995, now Pat. No. 5,809,437, and a continuation-in-part of application No. 10/079,065, filed on Feb. 19, 2002, now Pat. No. 6,662,642, which is a continuation-in-part of application No. 09/765,558, filed on Jan. 19, 2001, now Pat. No. 6,748,797.
- (60) Provisional application No. 60/231,378, filed on Sep. 8, 2000, provisional application No. 60/269,415, filed on Feb. 16, 2001, provisional application No. 60/291,511, filed on May 16, 2001, and provisional application No. 60/304,013, filed on Jul. 9, 2001.
- (51) **Int. Cl.⁷** **G06F 7/00**
- (52) **U.S. Cl.** **701/36; 701/29; 701/34**
- (58) **Field of Search** **701/29, 34, 36, 701/45; 307/9.1**

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US 6,850,824 B2

Page 2

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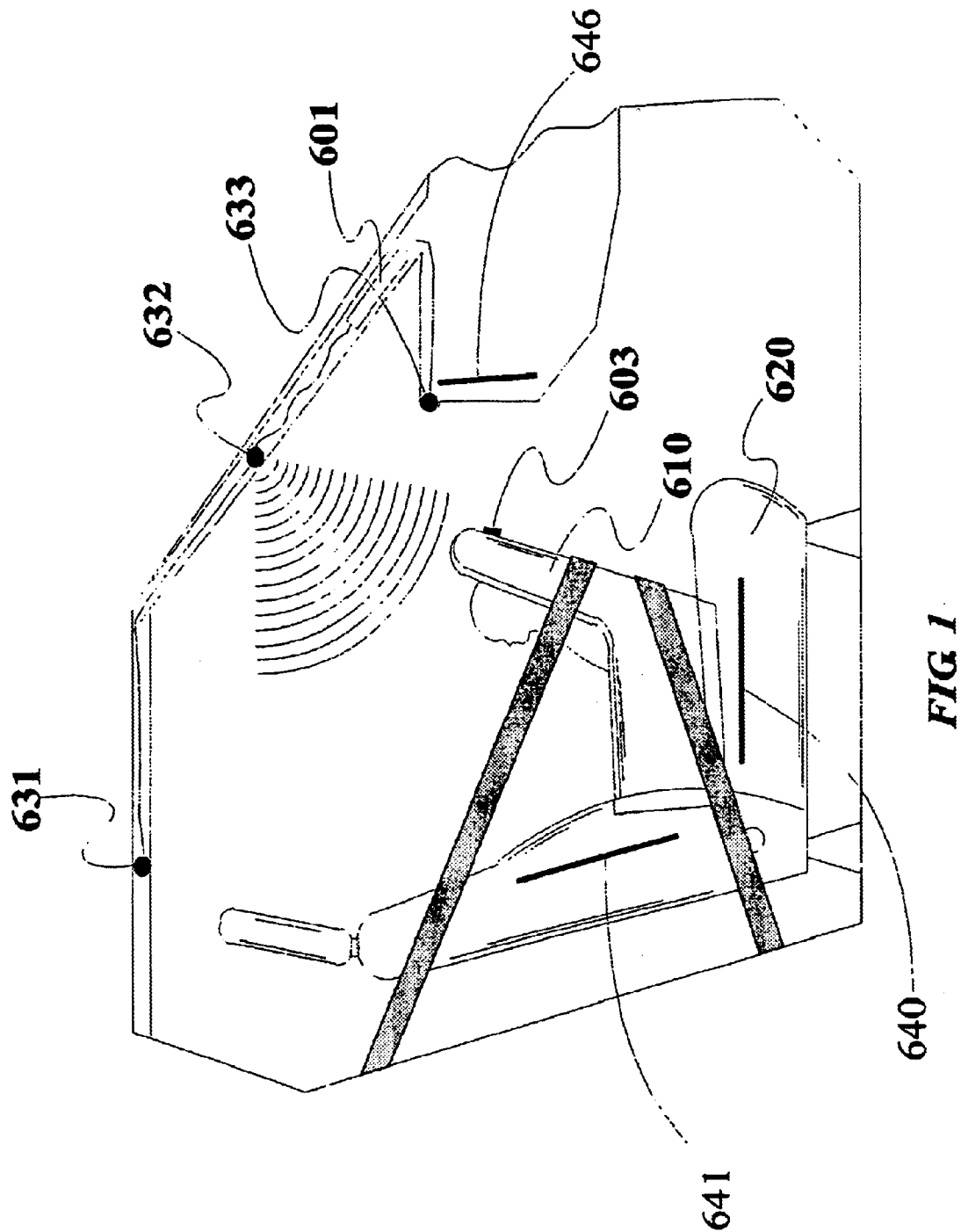
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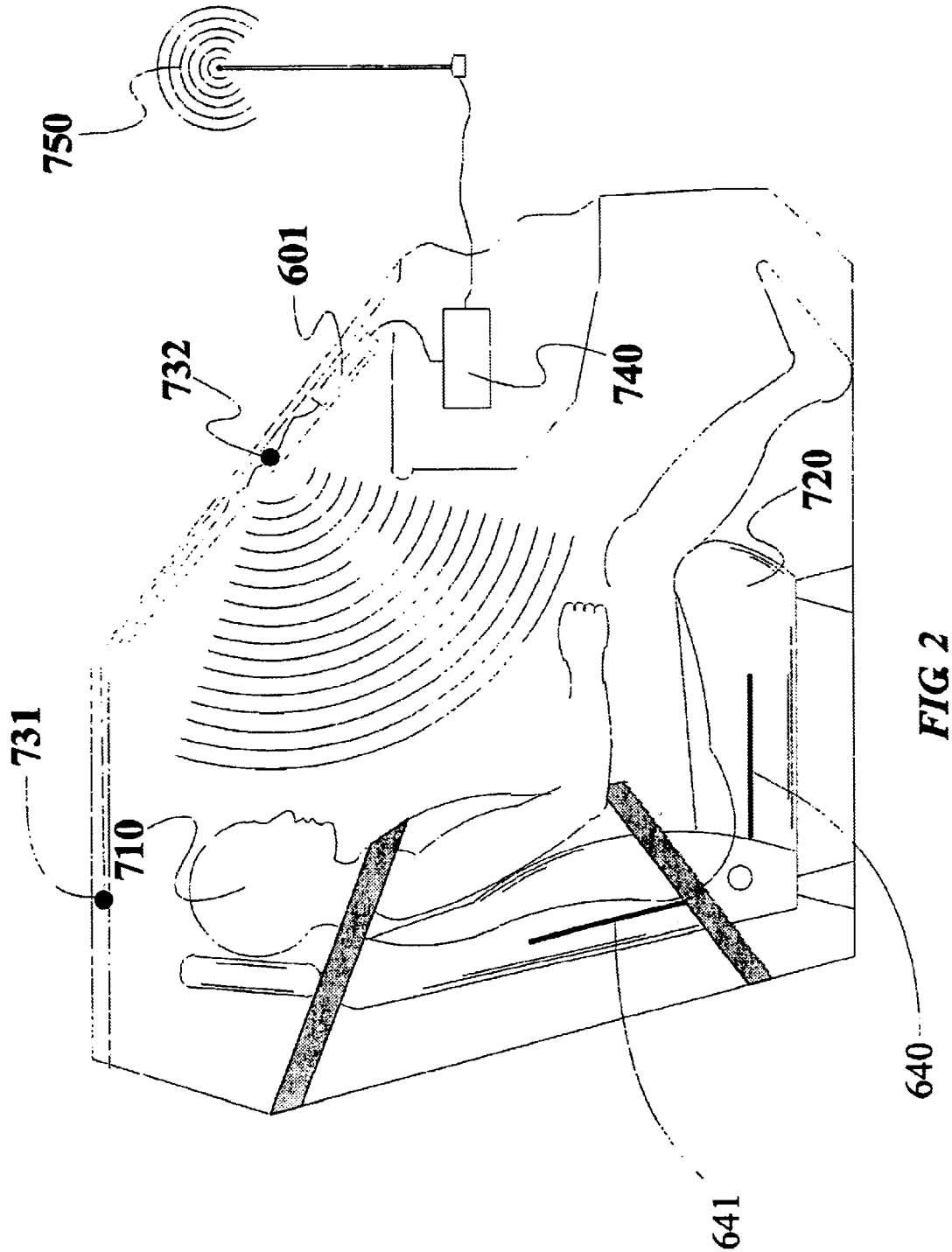
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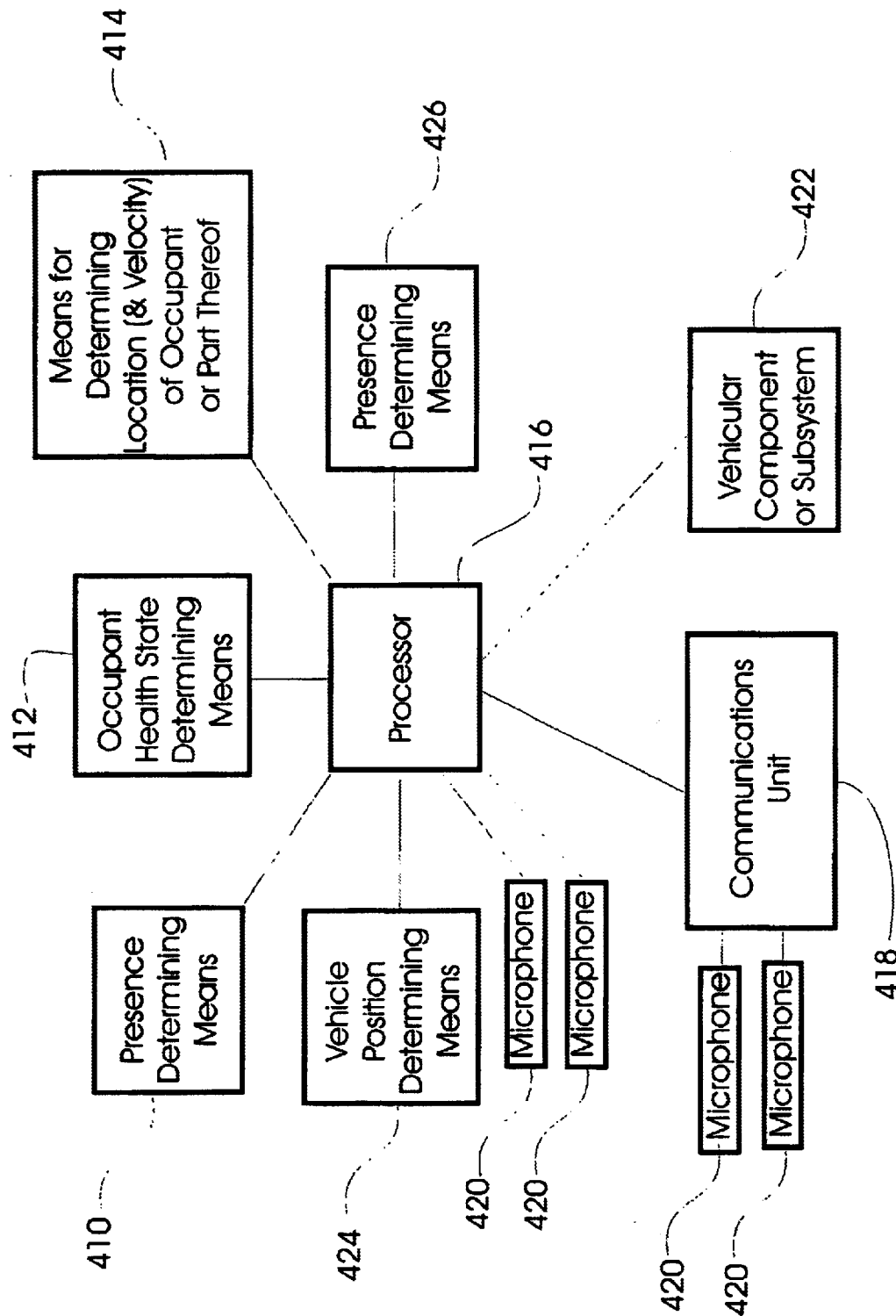


FIG 3

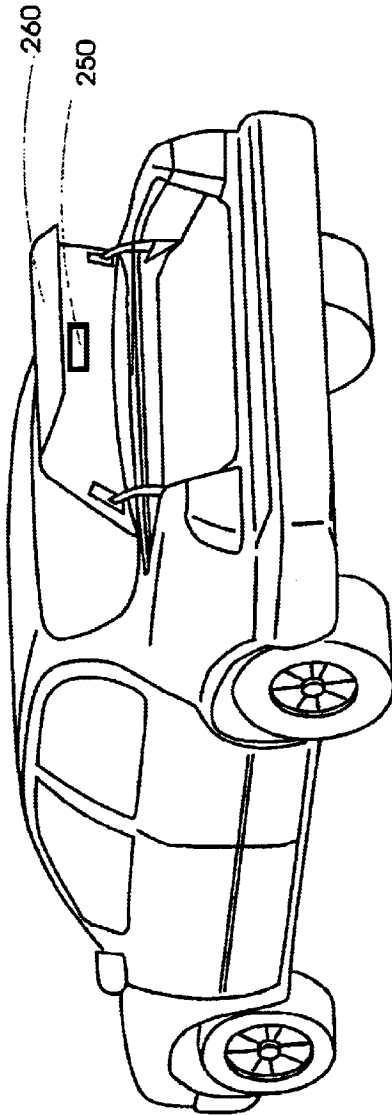


FIG. 4

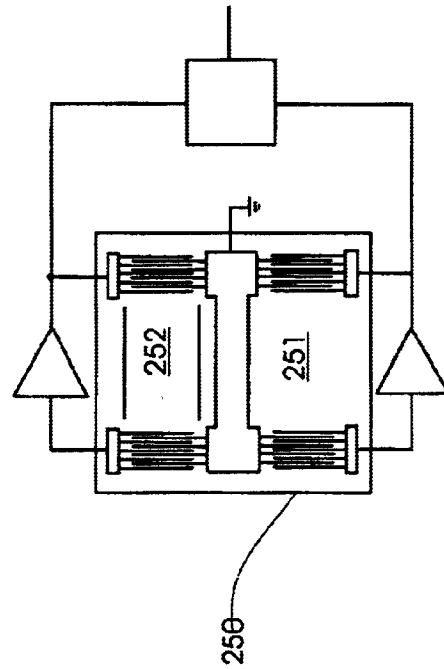


FIG. 4A

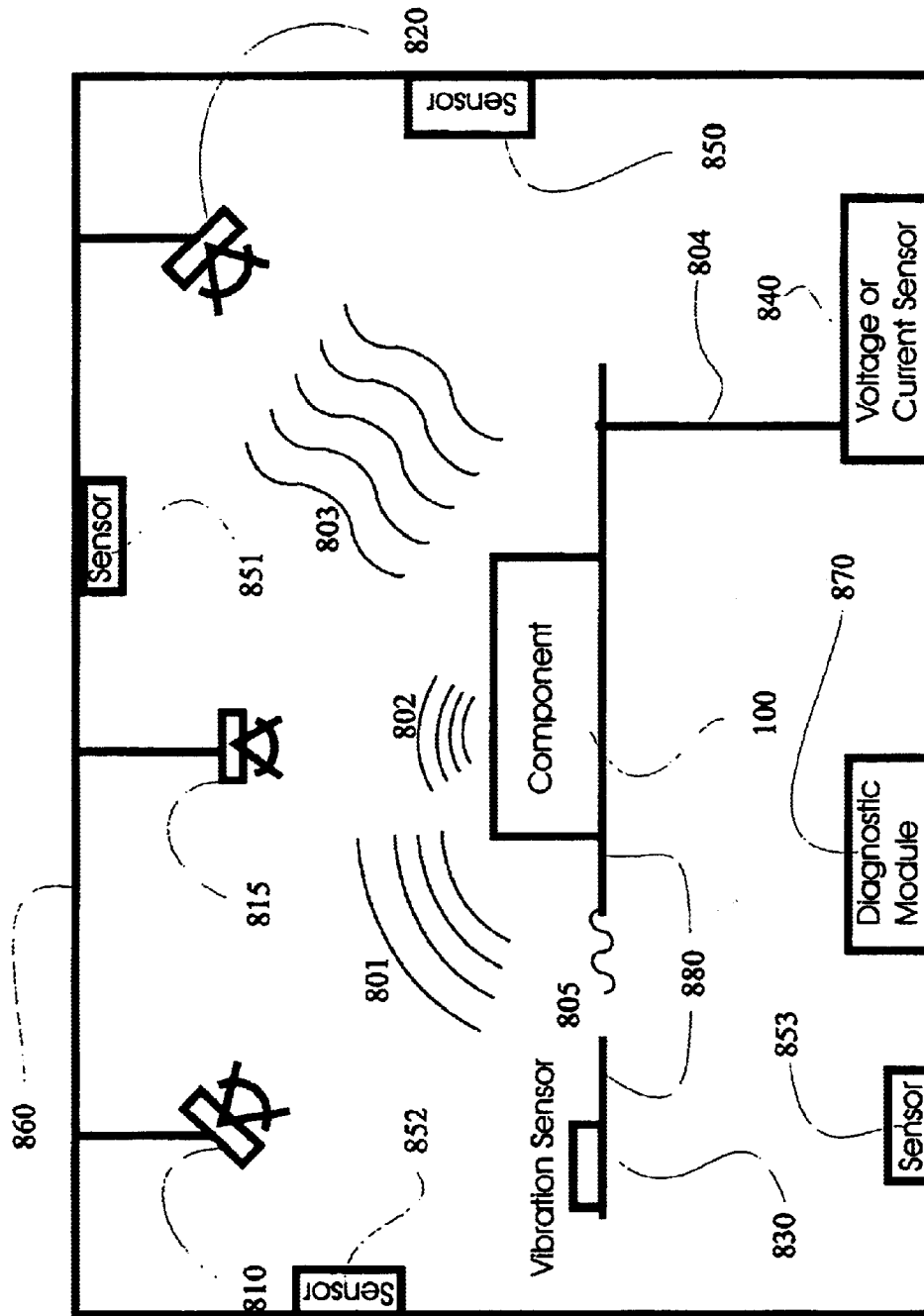


FIG. 5

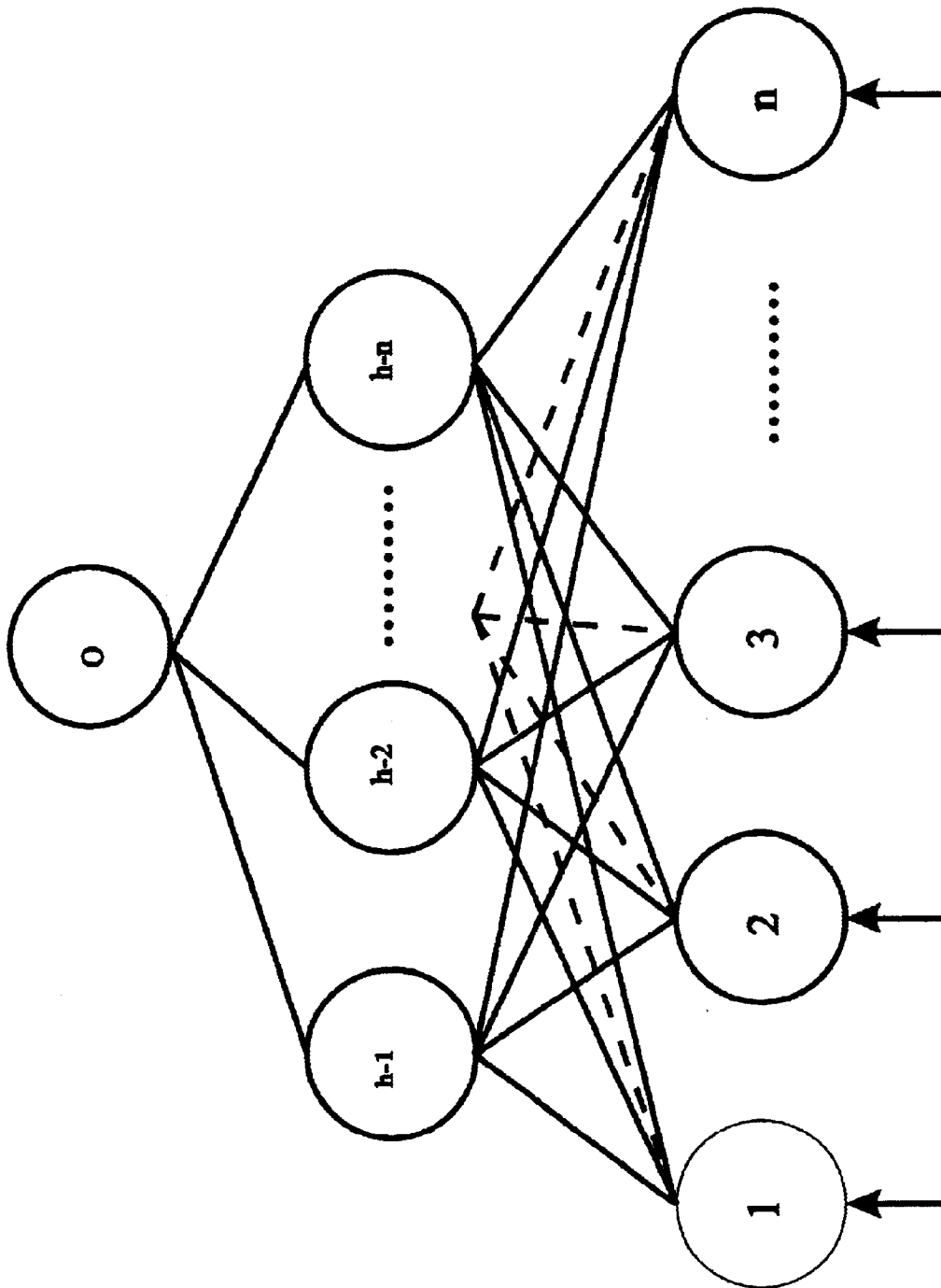


FIG 6

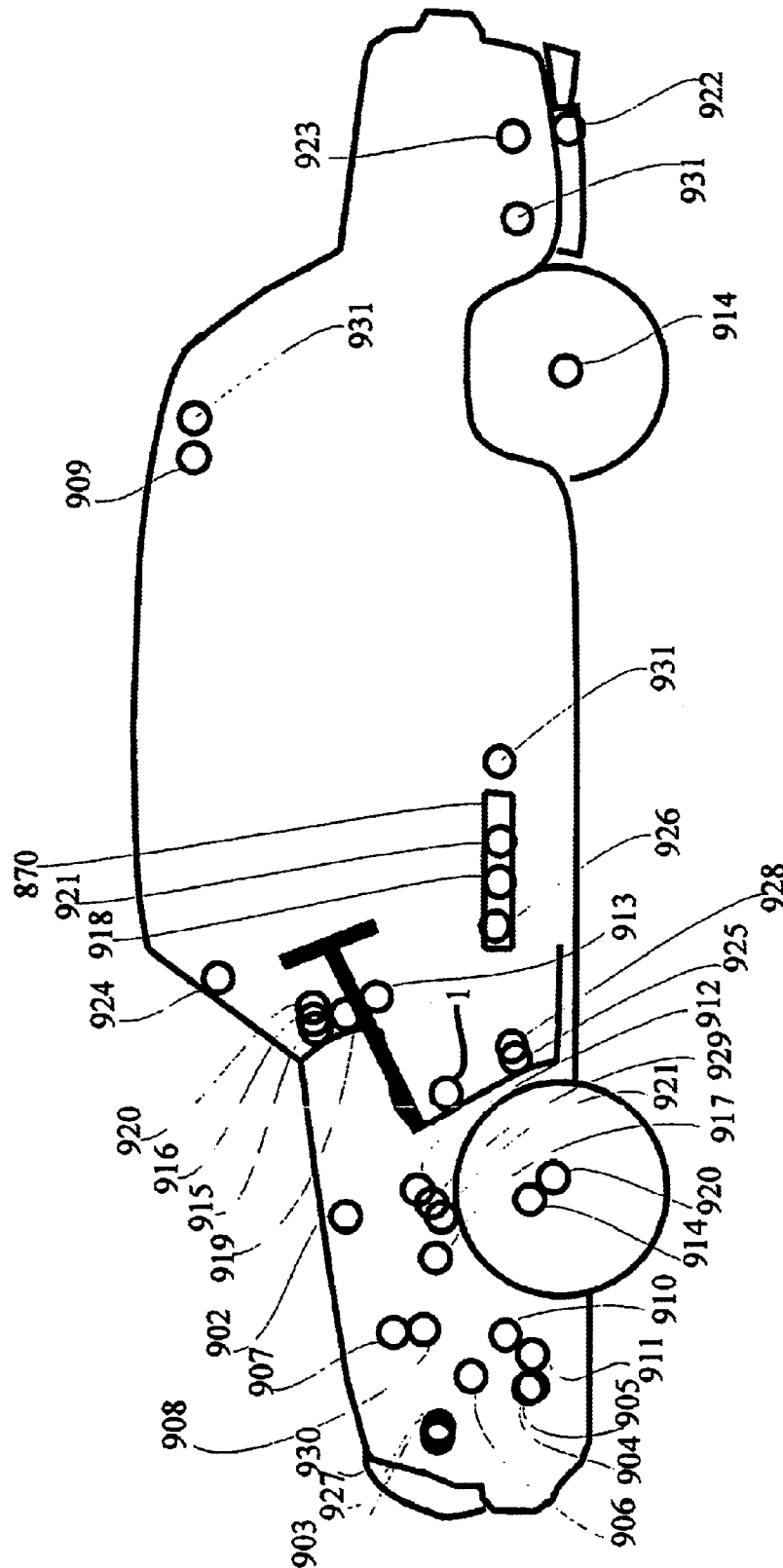


FIG 7

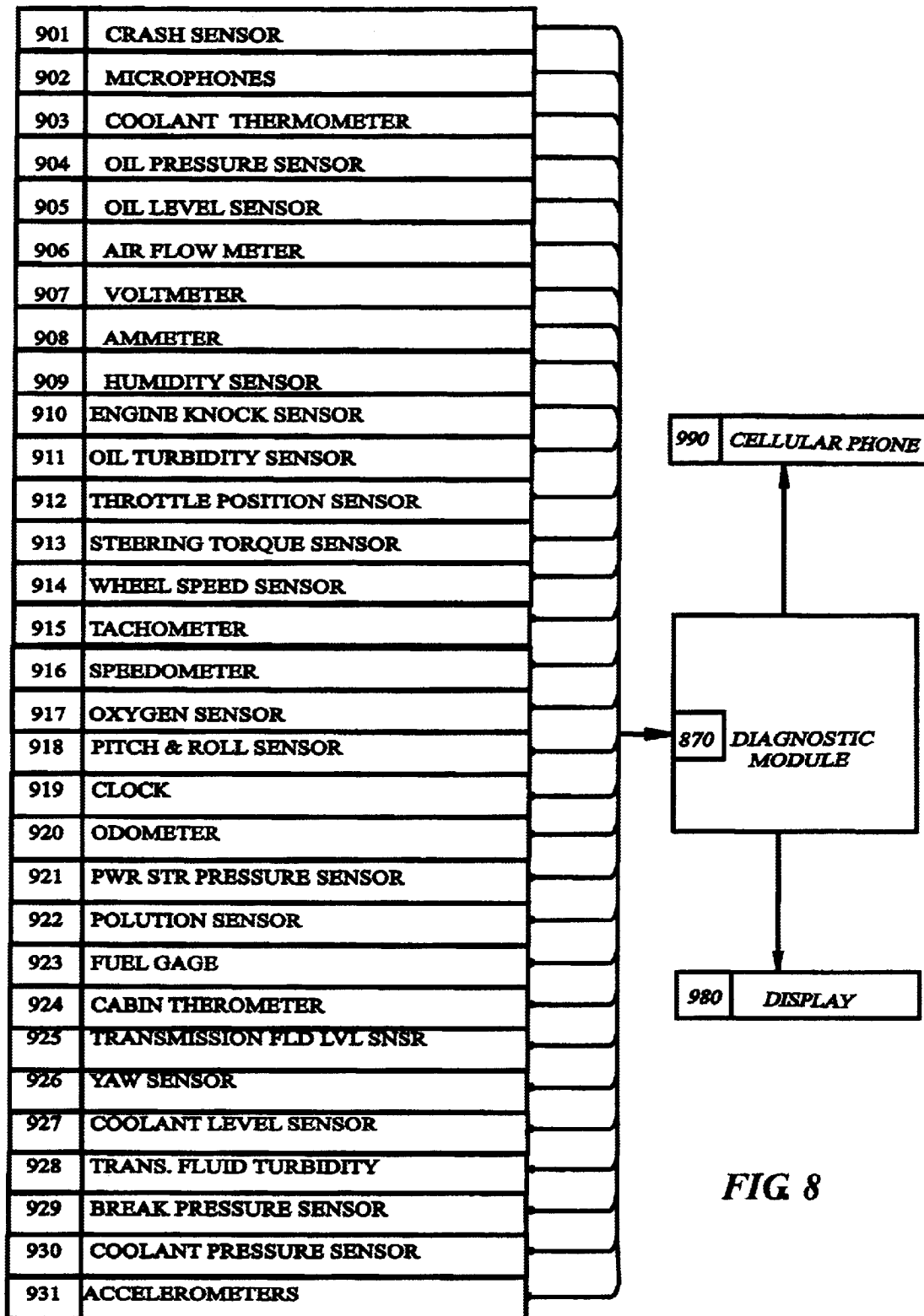
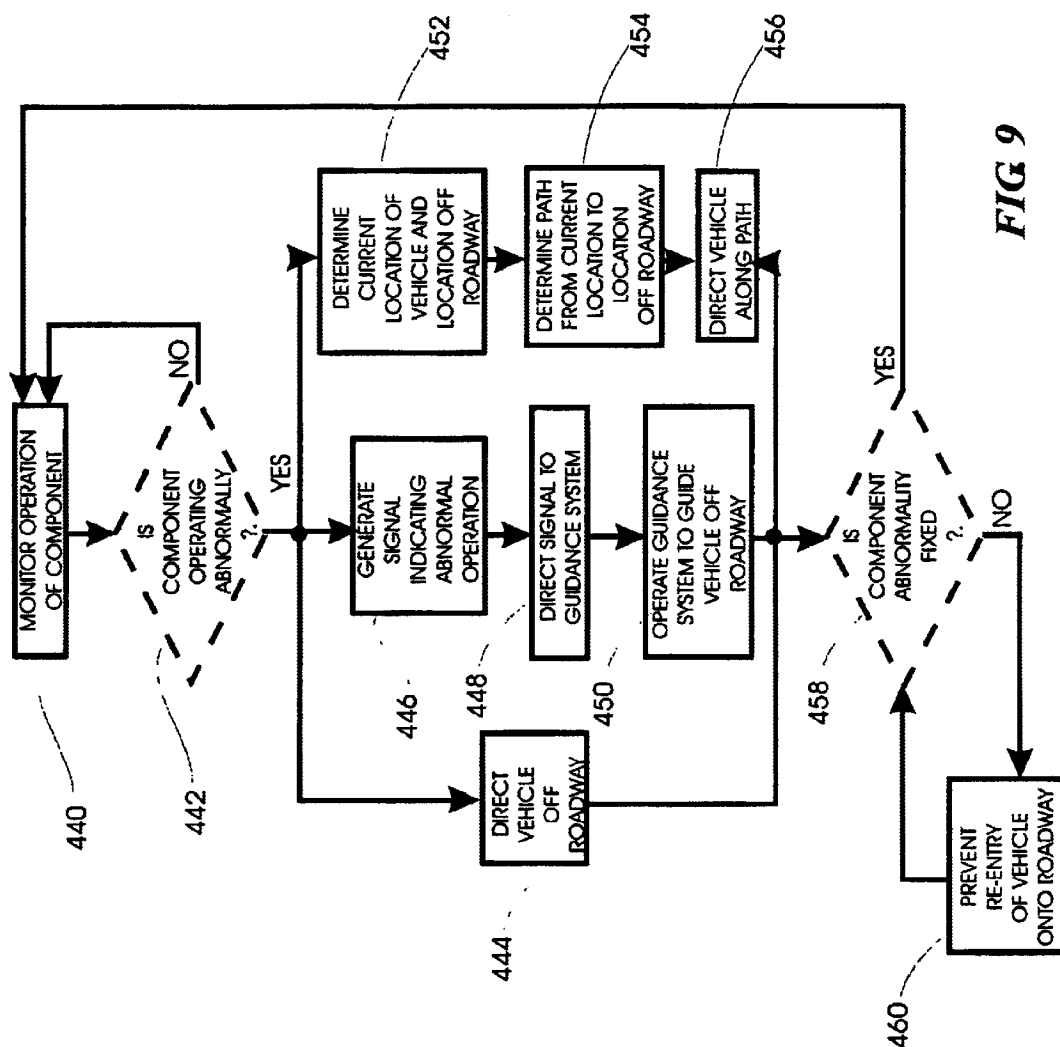


FIG 8



U.S. Patent

Feb. 1, 2005

Sheet 10 of 39

US 6,850,824 B2

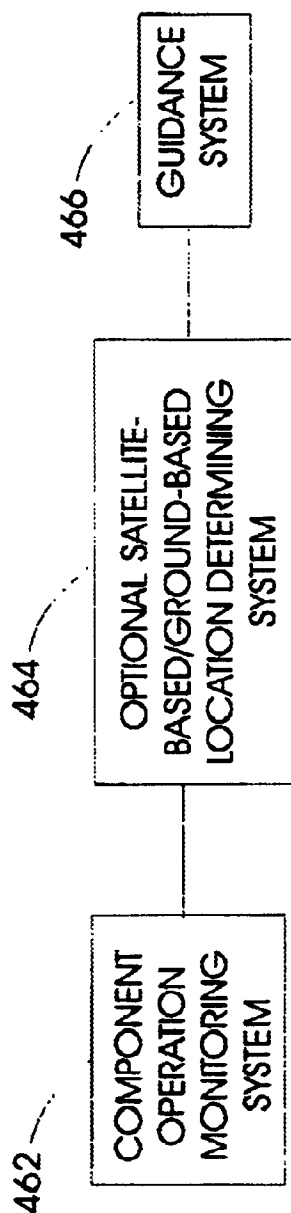


FIG 10

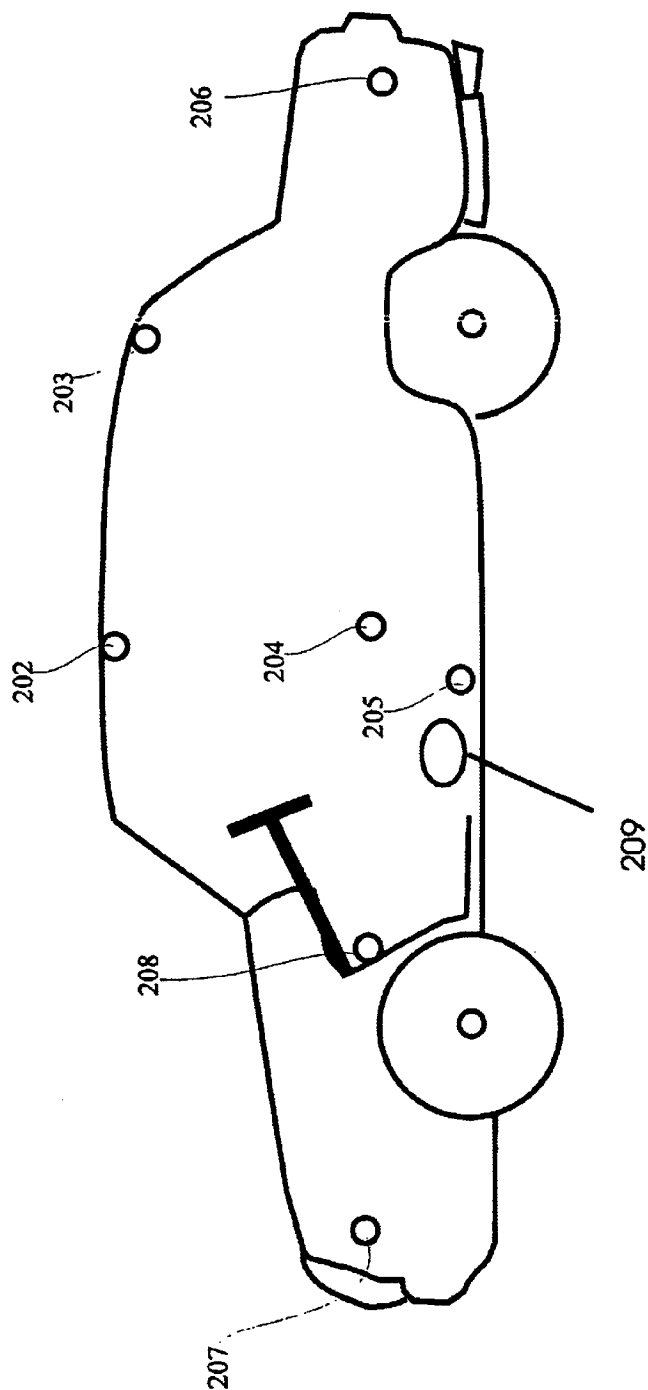


FIG 11

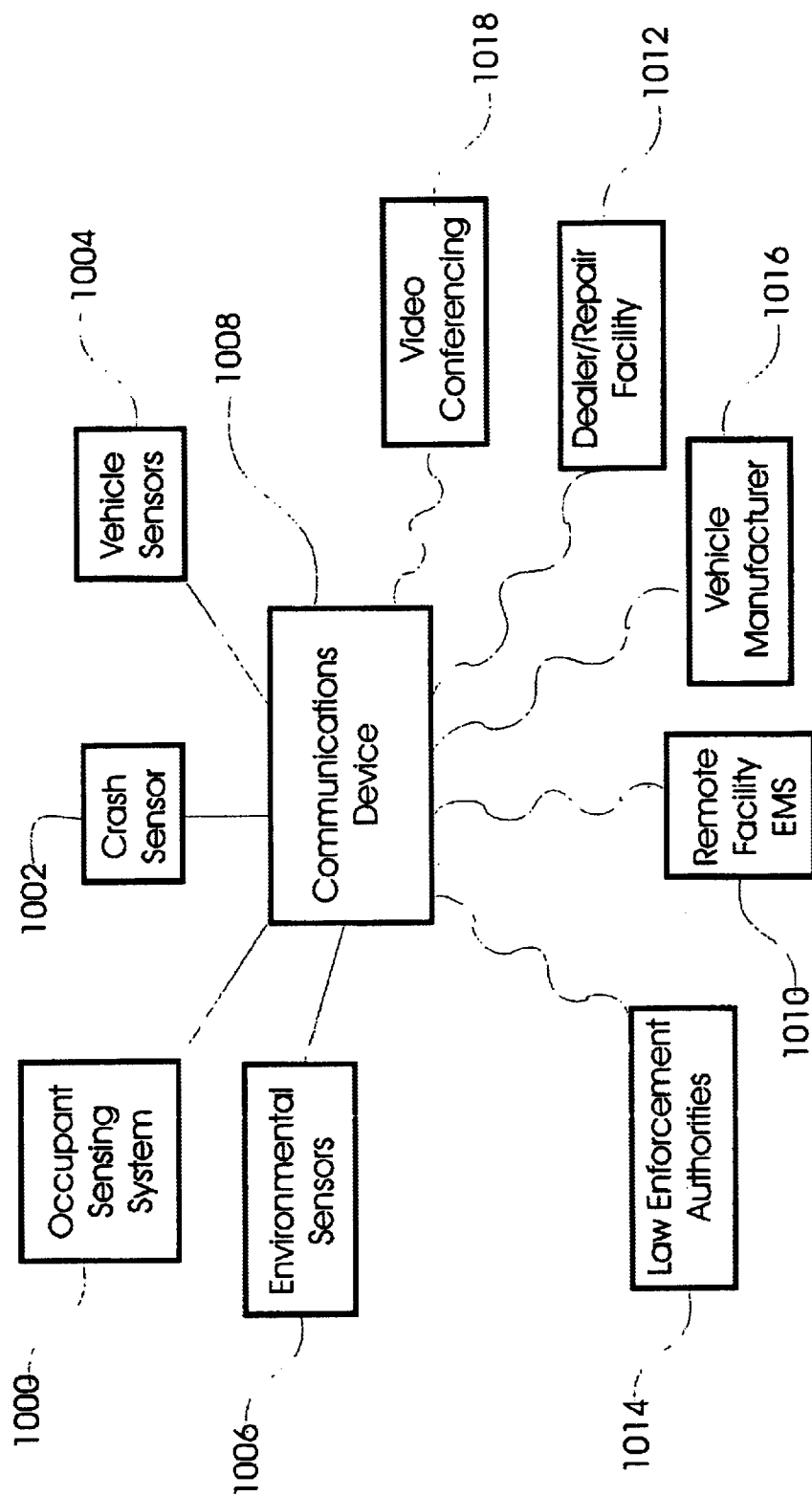


FIG 12

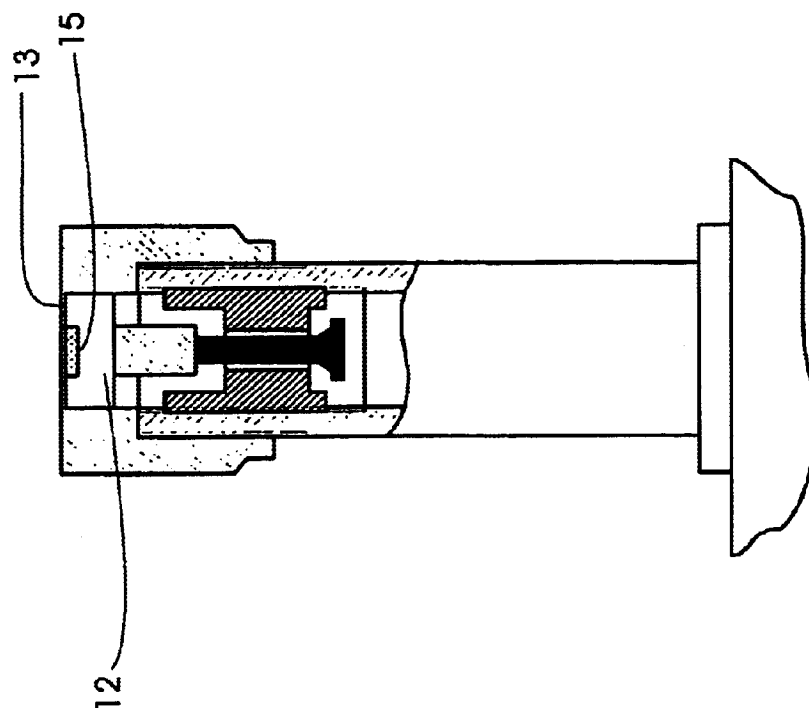


FIG. 13B

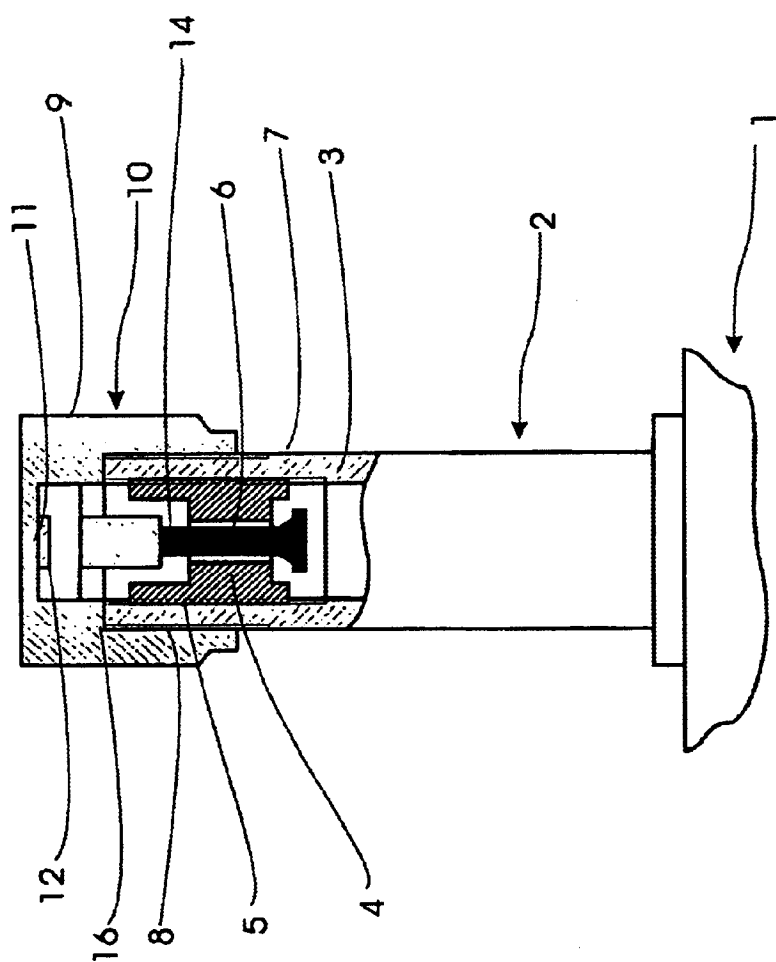


FIG. 13A

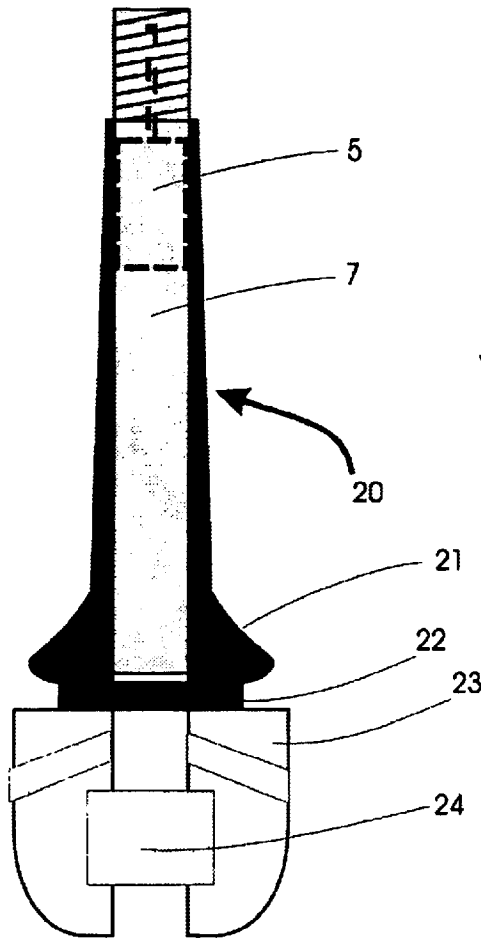


FIG. 14

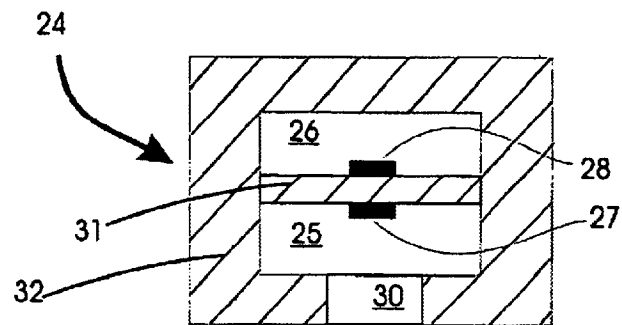


FIG. 14A

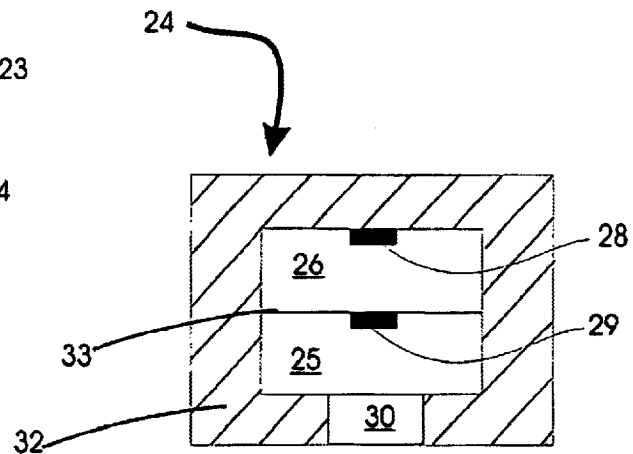


FIG. 14B

U.S. Patent

Feb. 1, 2005

Sheet 15 of 39

US 6,850,824 B2

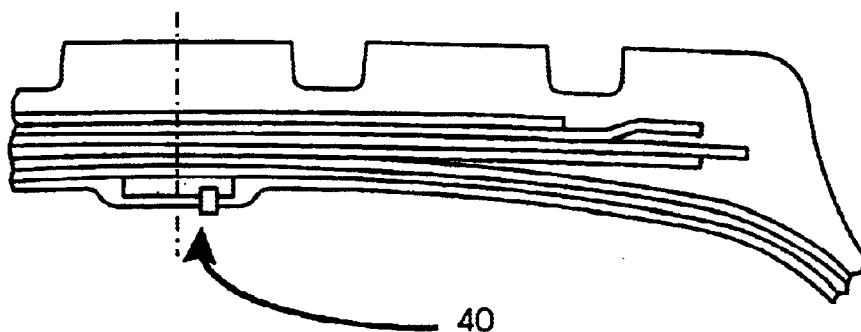


FIG. 15A

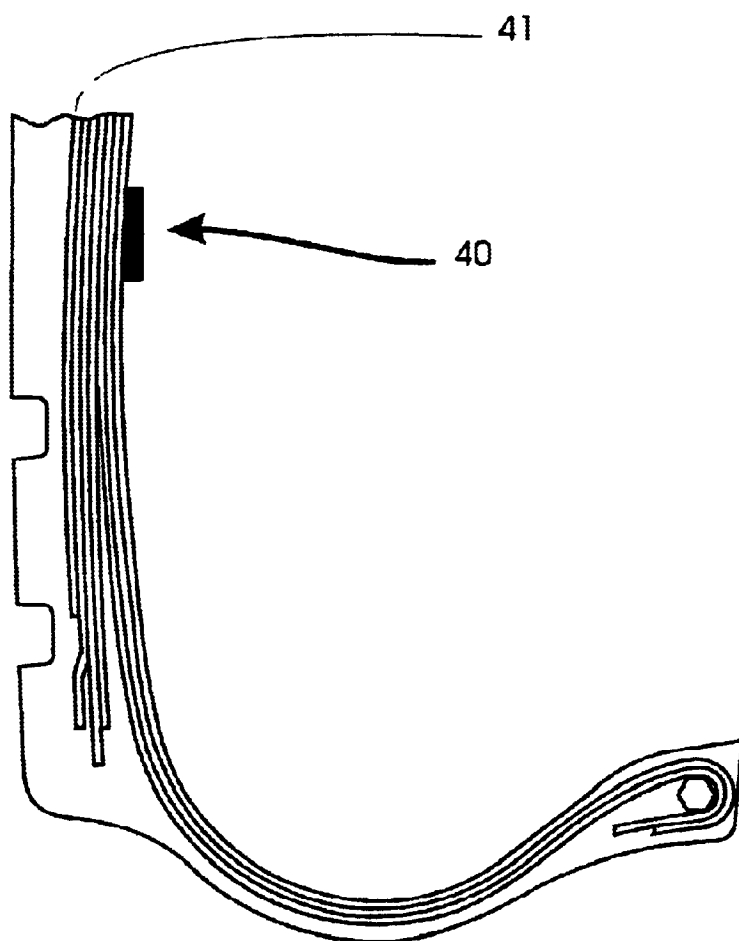
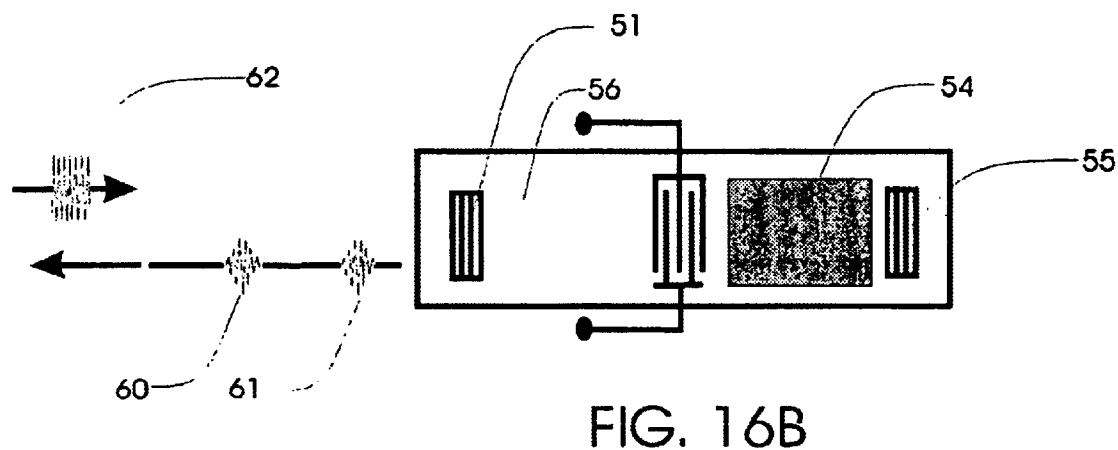
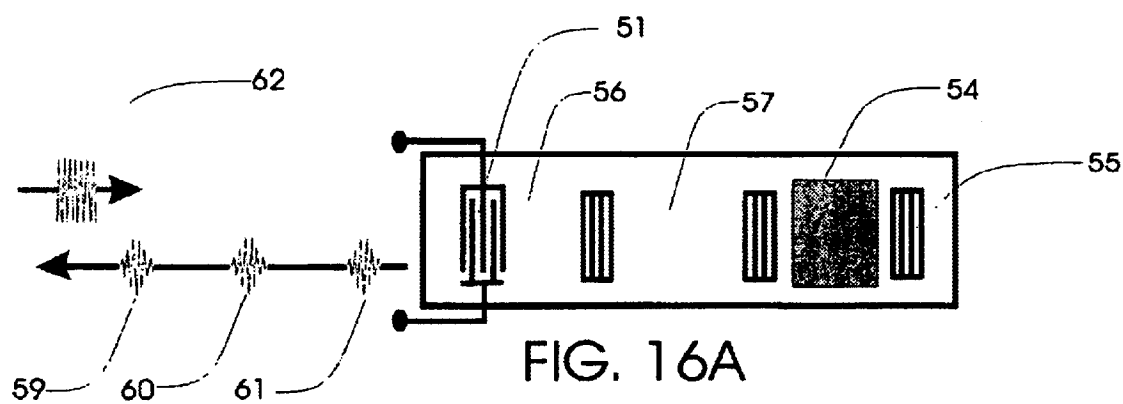
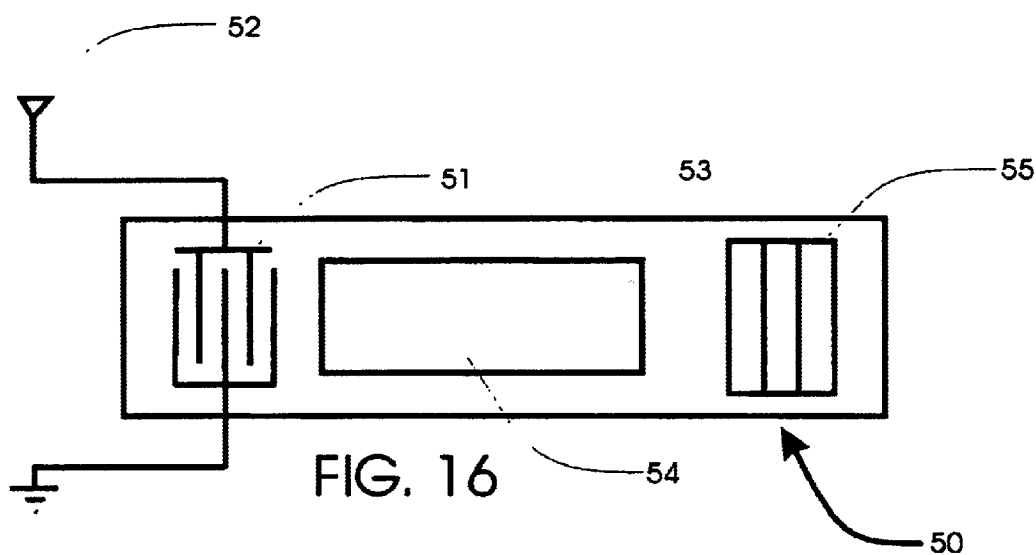


FIG. 15



U.S. Patent

Feb. 1, 2005

Sheet 17 of 39

US 6,850,824 B2

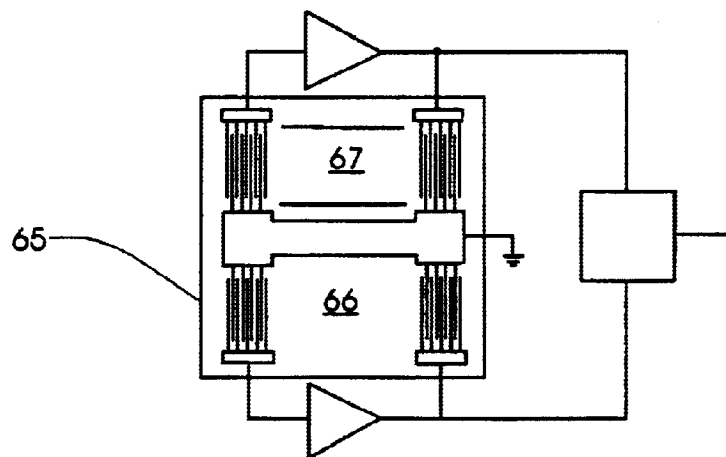


FIG. 17B

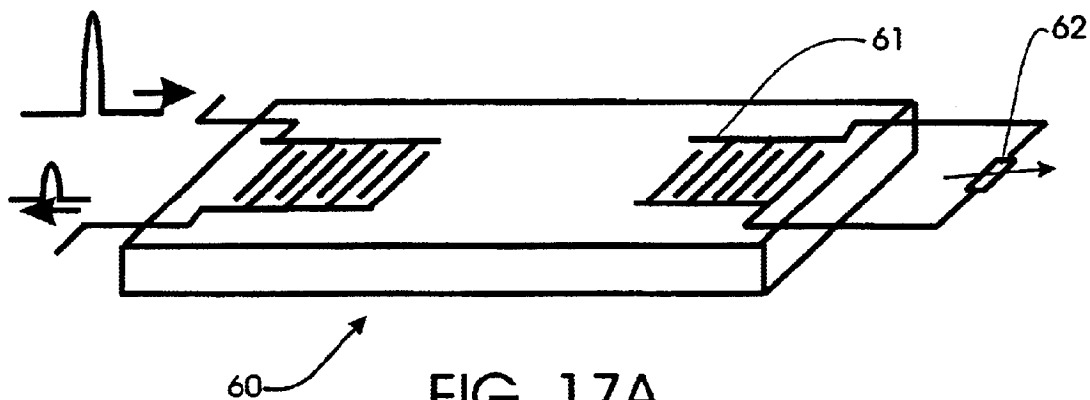


FIG. 17A

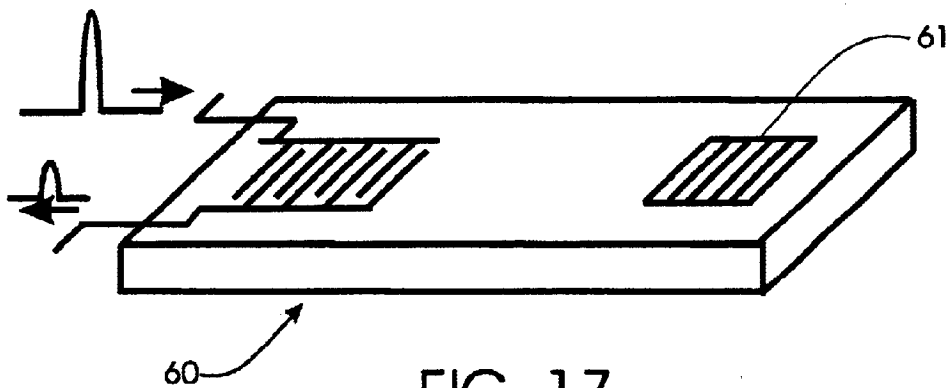


FIG. 17

U.S. Patent

Feb. 1, 2005

Sheet 18 of 39

US 6,850,824 B2

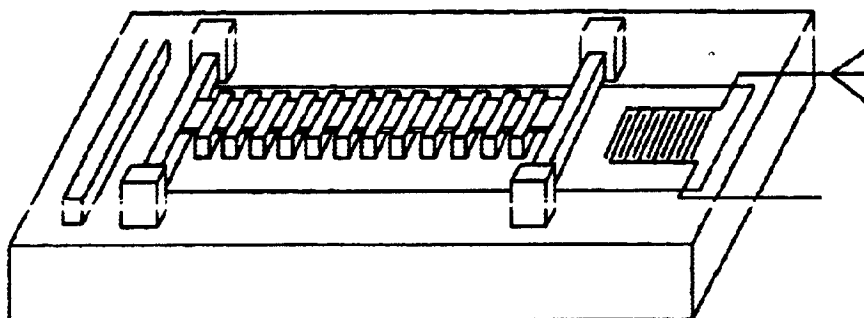


FIG. 18A
PRIOR ART

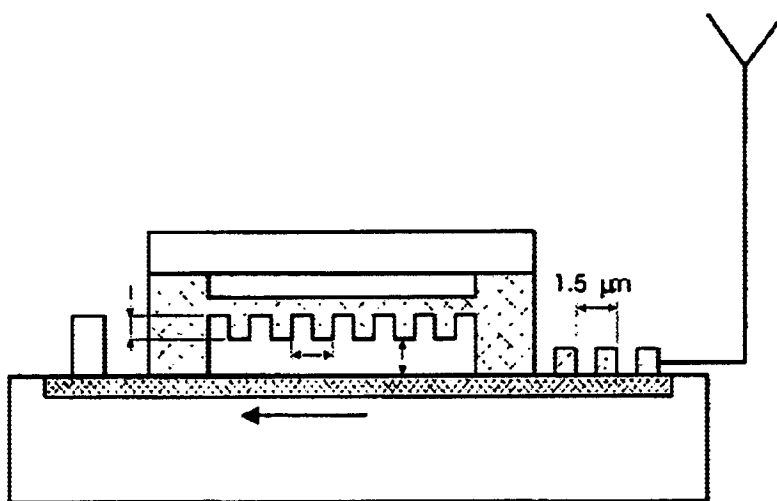


FIG. 18
PRIOR ART

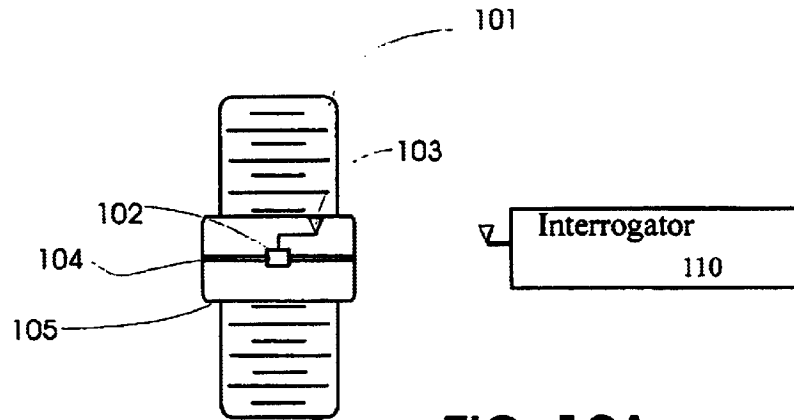


FIG. 19A

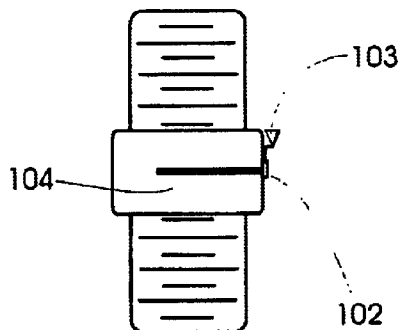


FIG. 19B

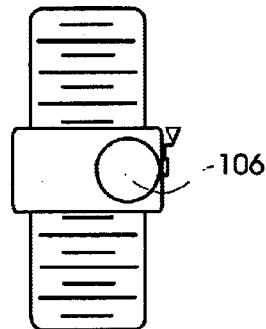


FIG. 19C

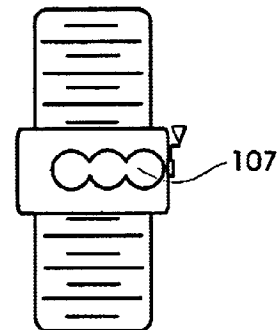


FIG. 19D

U.S. Patent

Feb. 1, 2005

Sheet 20 of 39

US 6,850,824 B2

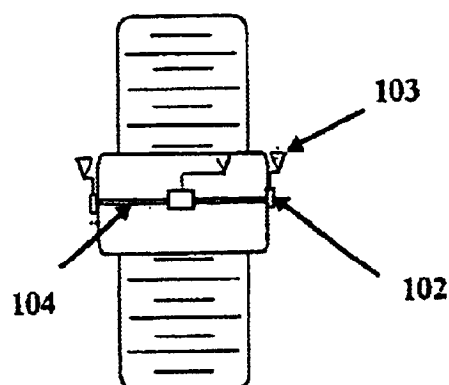


FIG. 19E

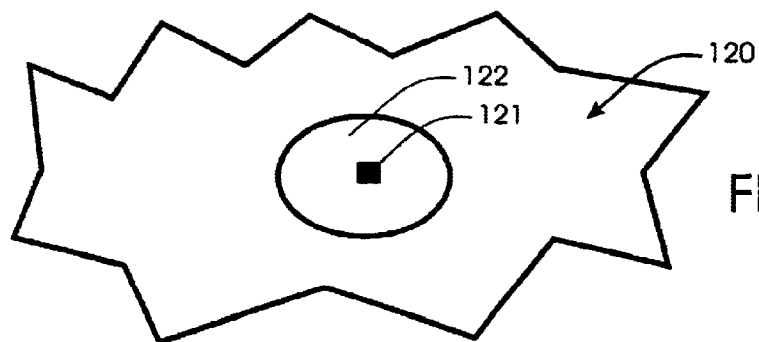


FIG. 20A

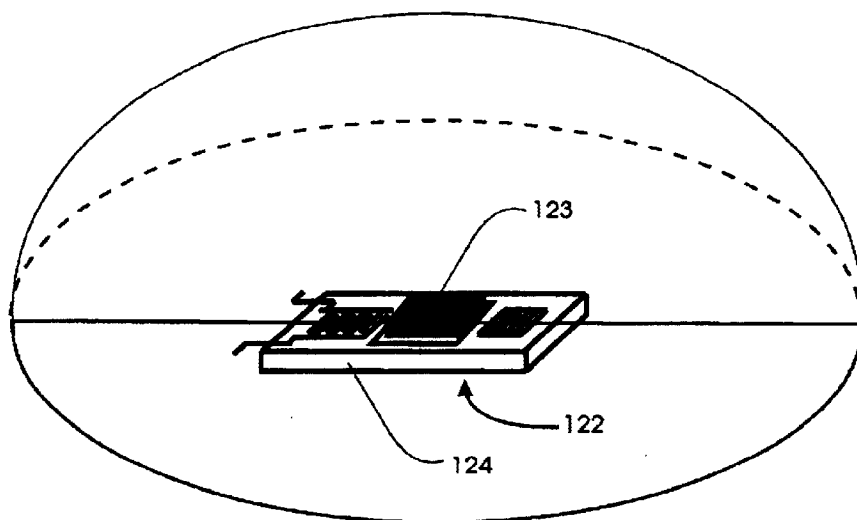


FIG. 20B

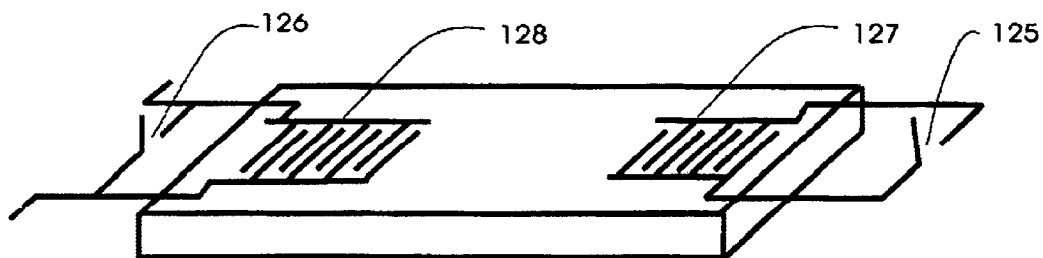


FIG. 20C

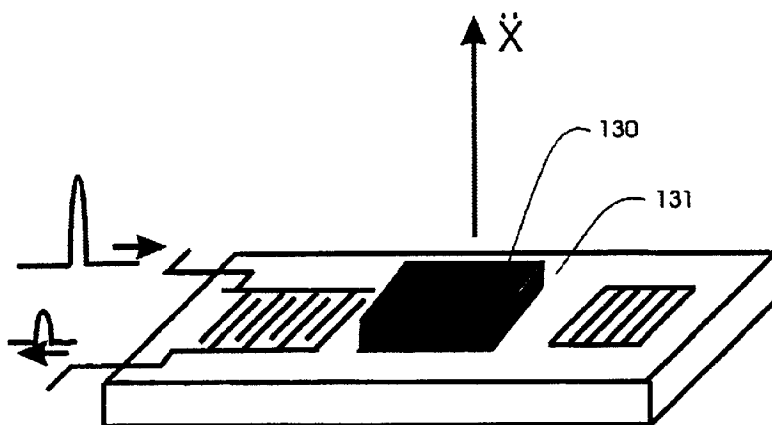


FIG. 21A

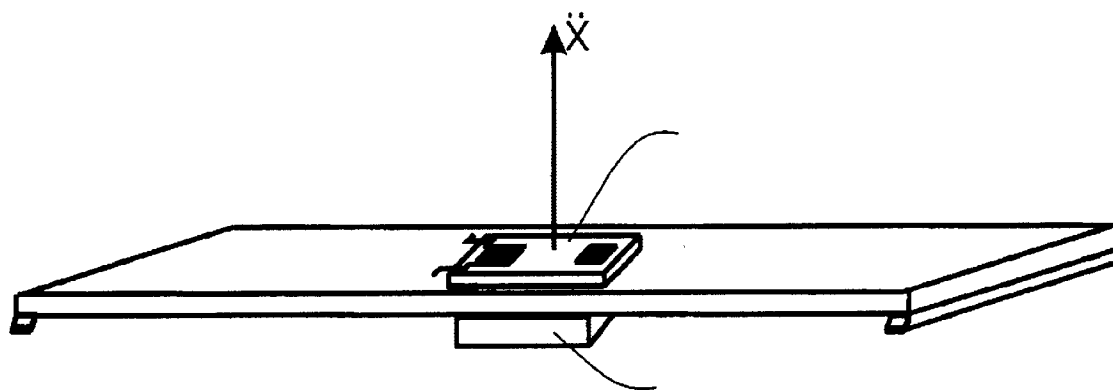


FIG. 21B

Prior Art

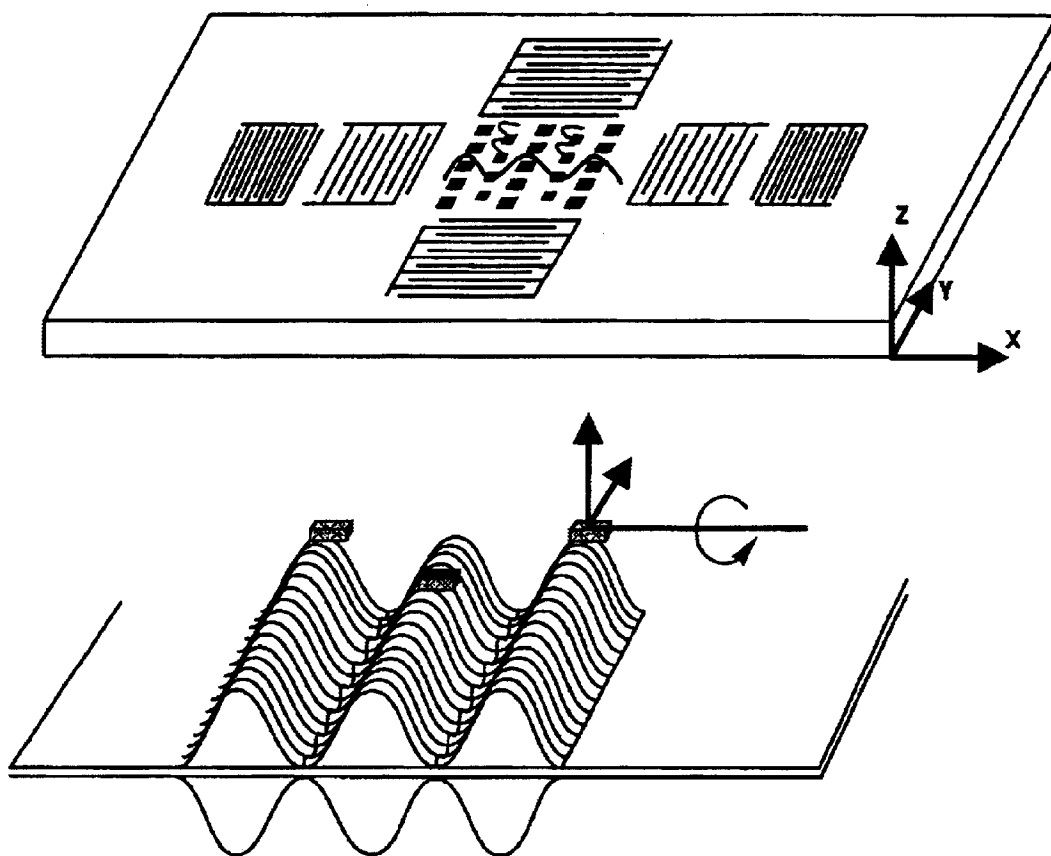


FIG. 22

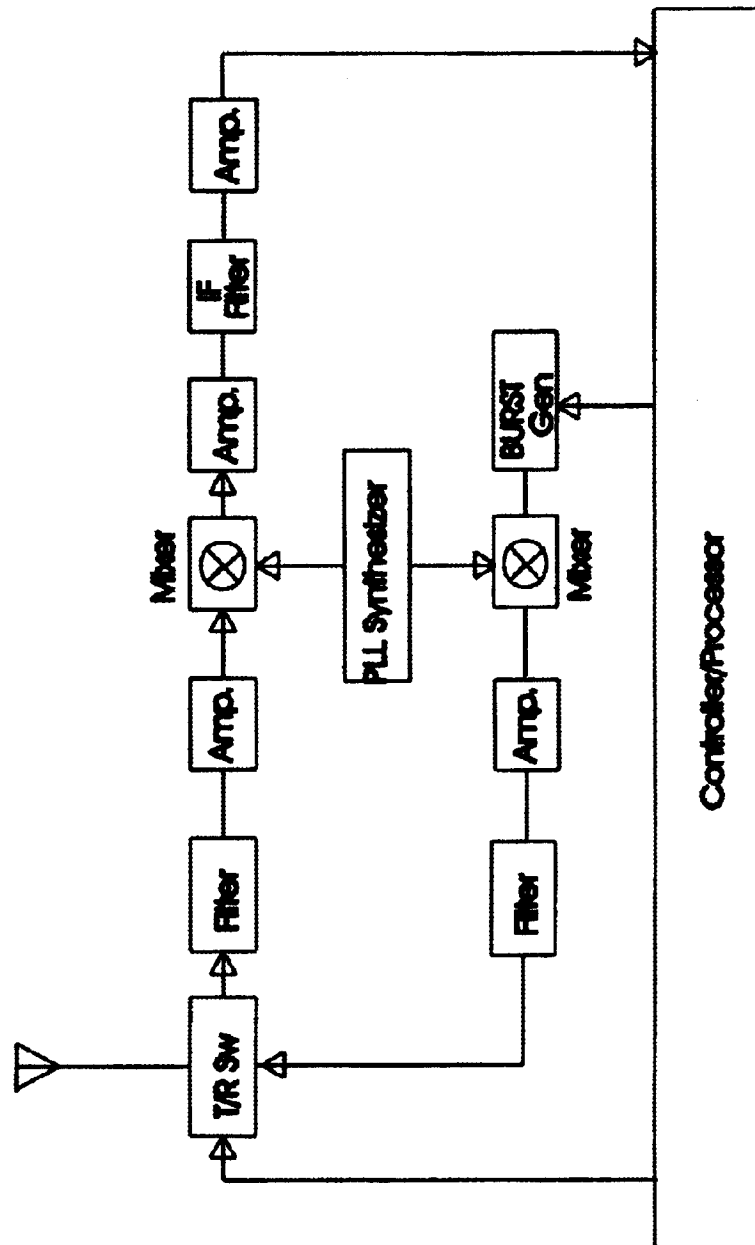


FIG. 23A

U.S. Patent

Feb. 1, 2005

Sheet 25 of 39

US 6,850,824 B2

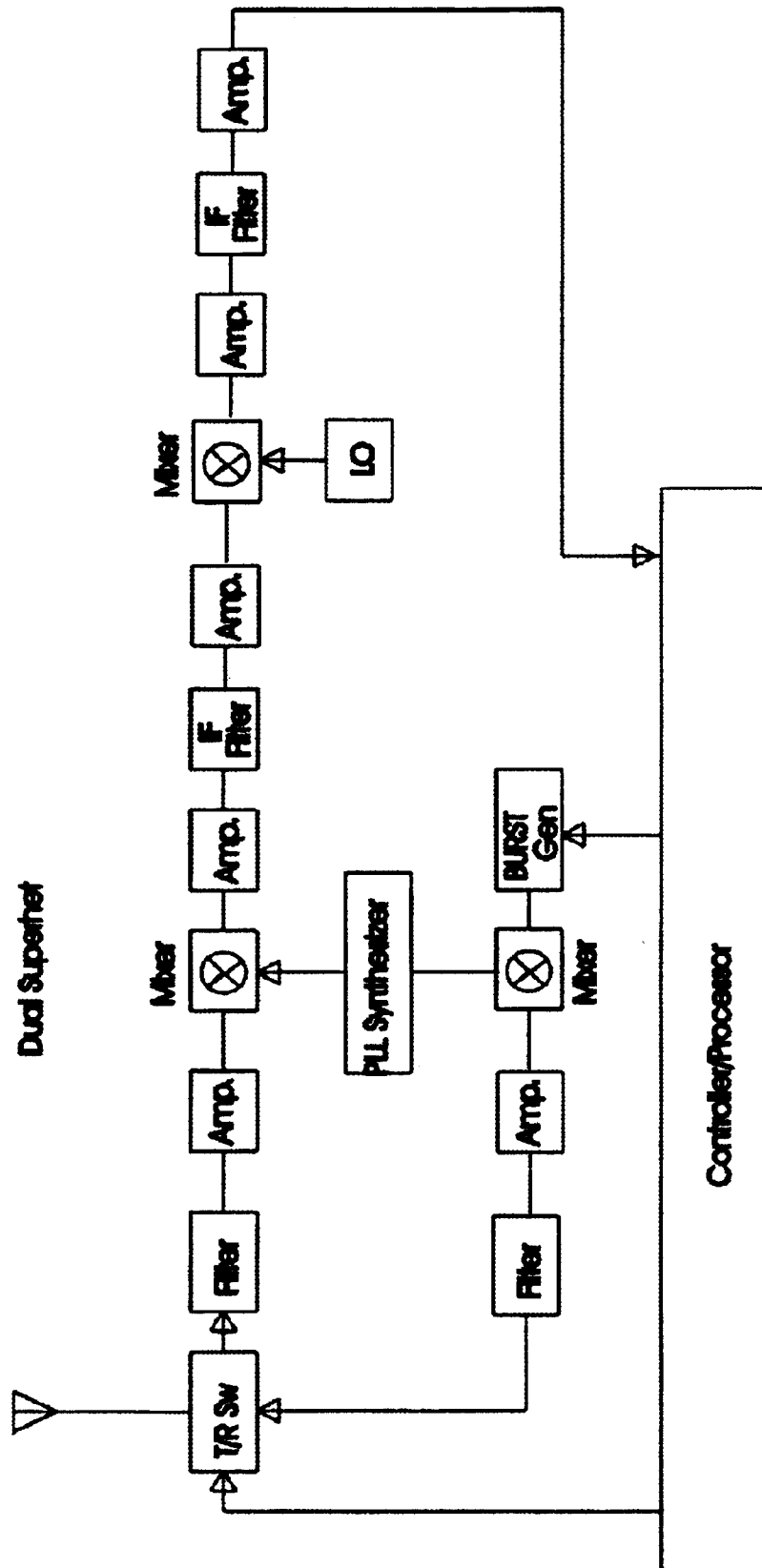


FIG. 23B

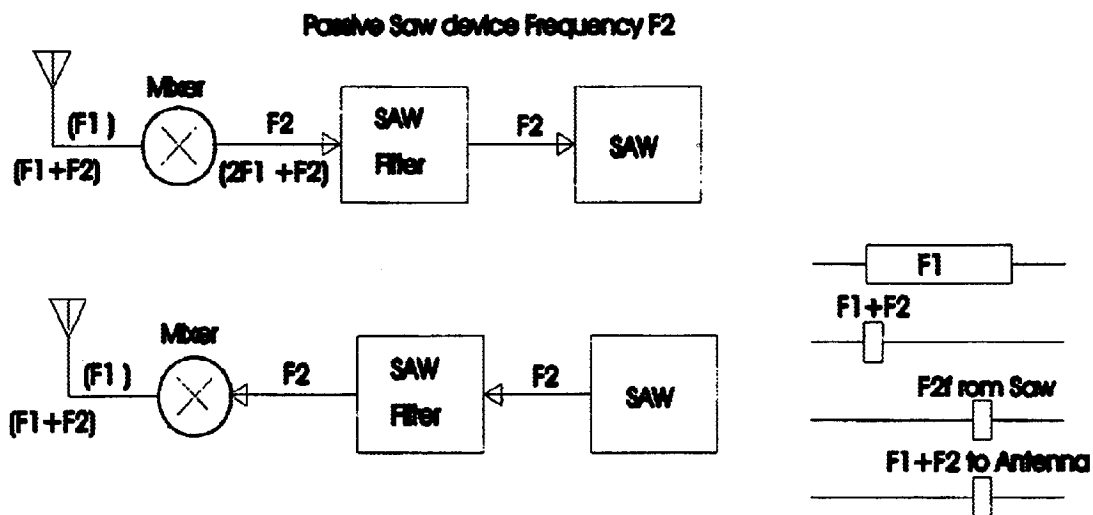
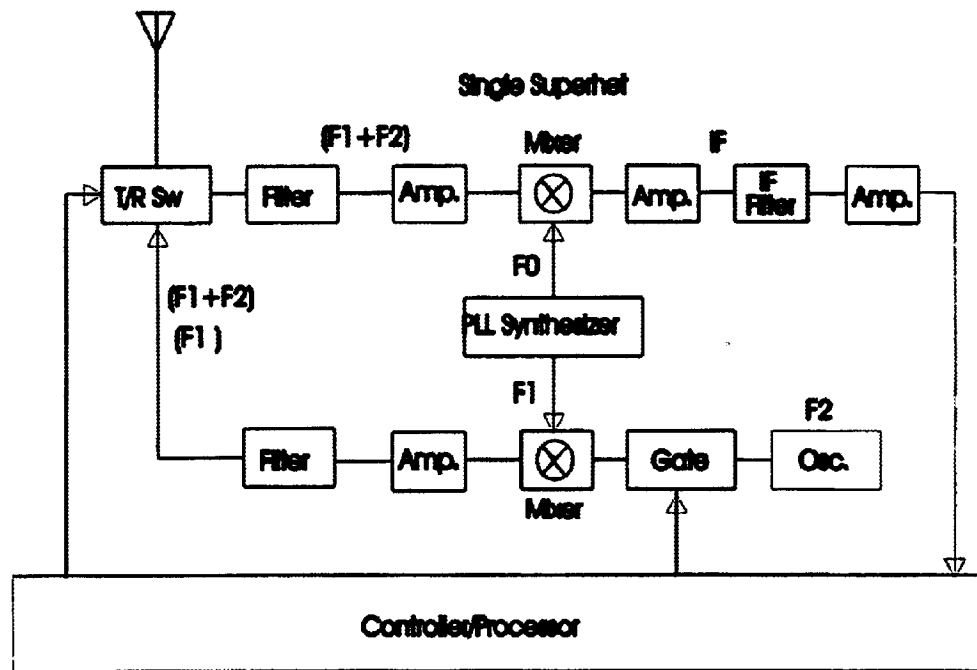


FIG. 23C

U.S. Patent

Feb. 1, 2005

Sheet 27 of 39

US 6,850,824 B2

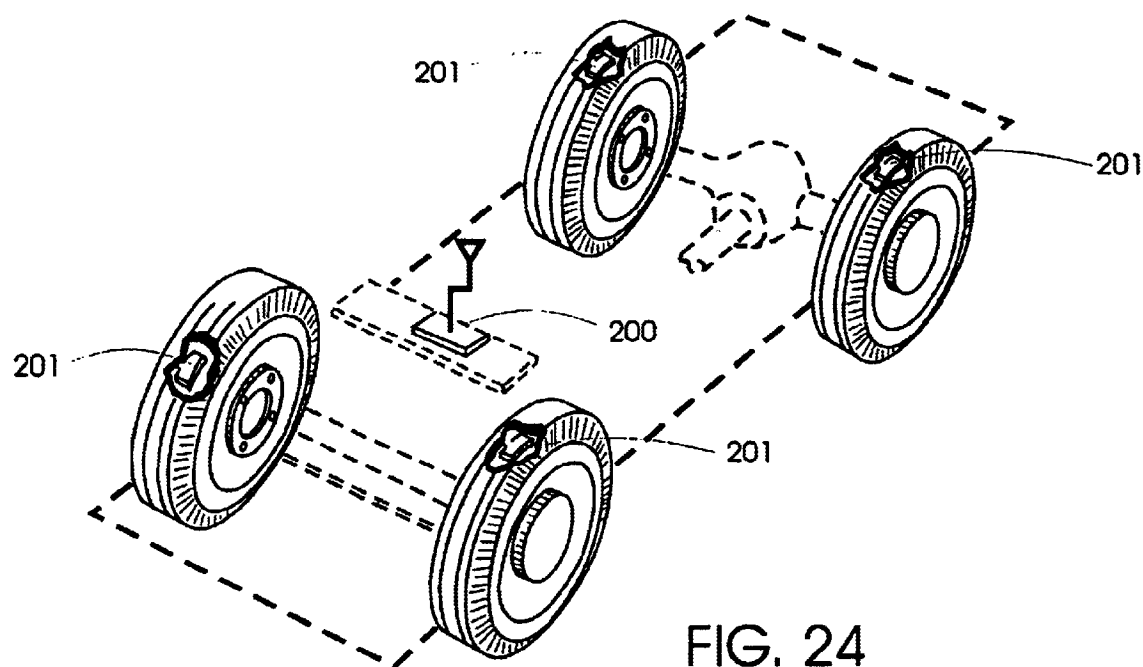


FIG. 24

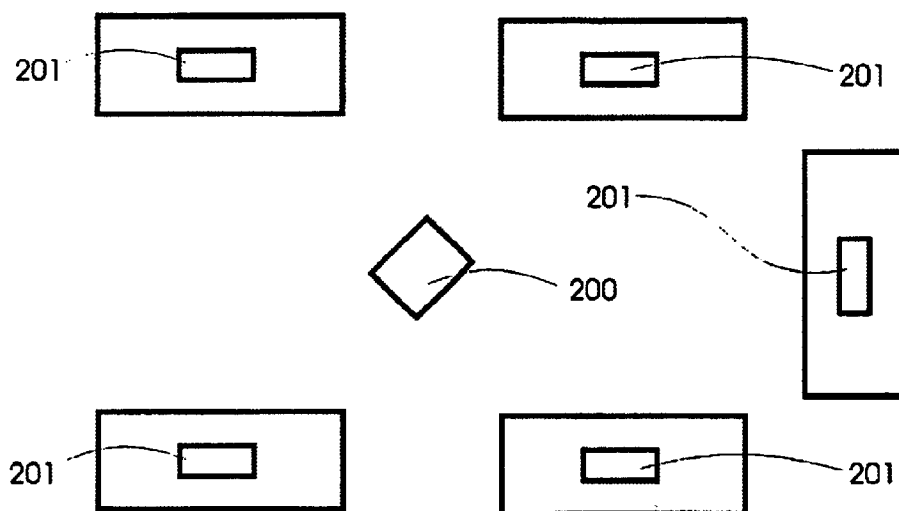


FIG. 24A

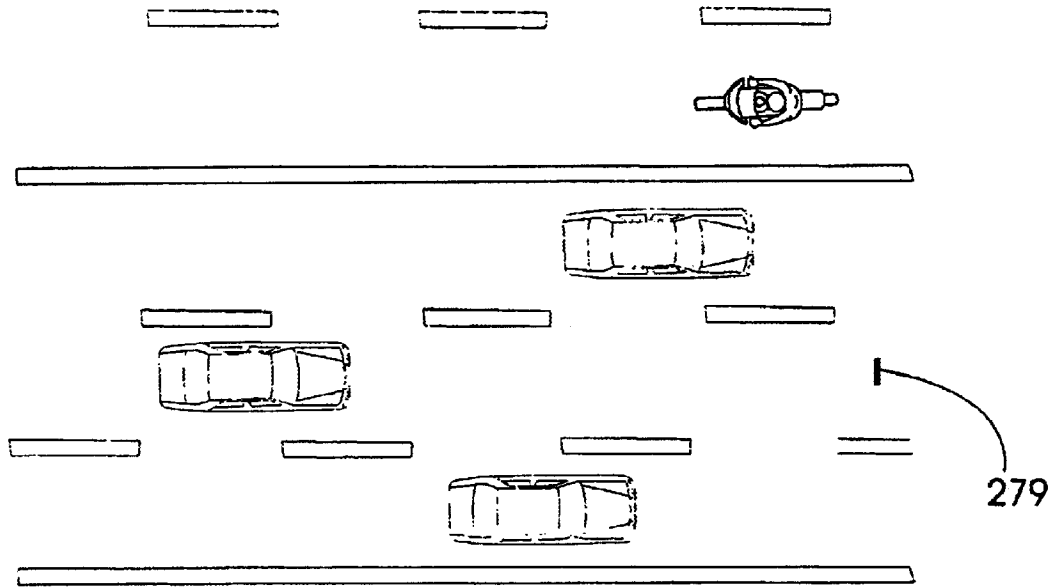


FIG. 25

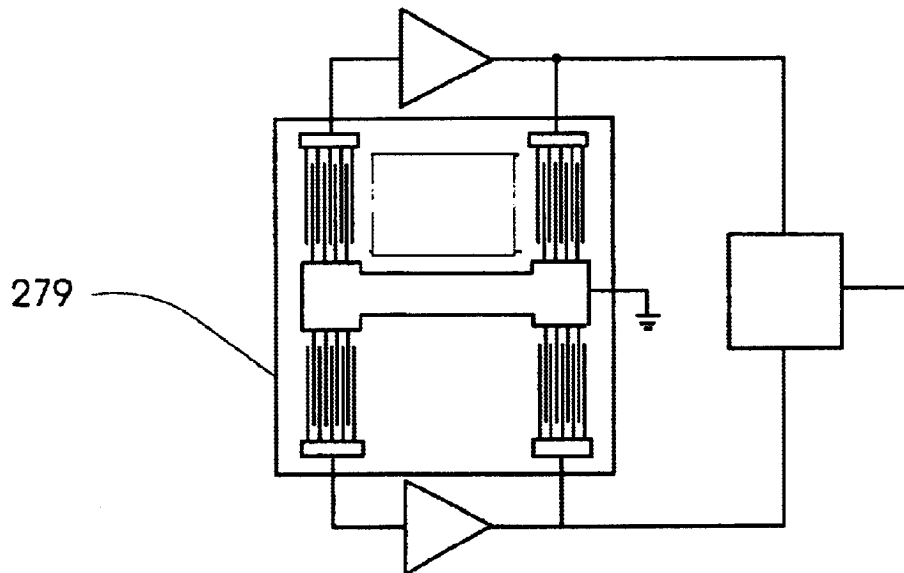


FIG. 25A

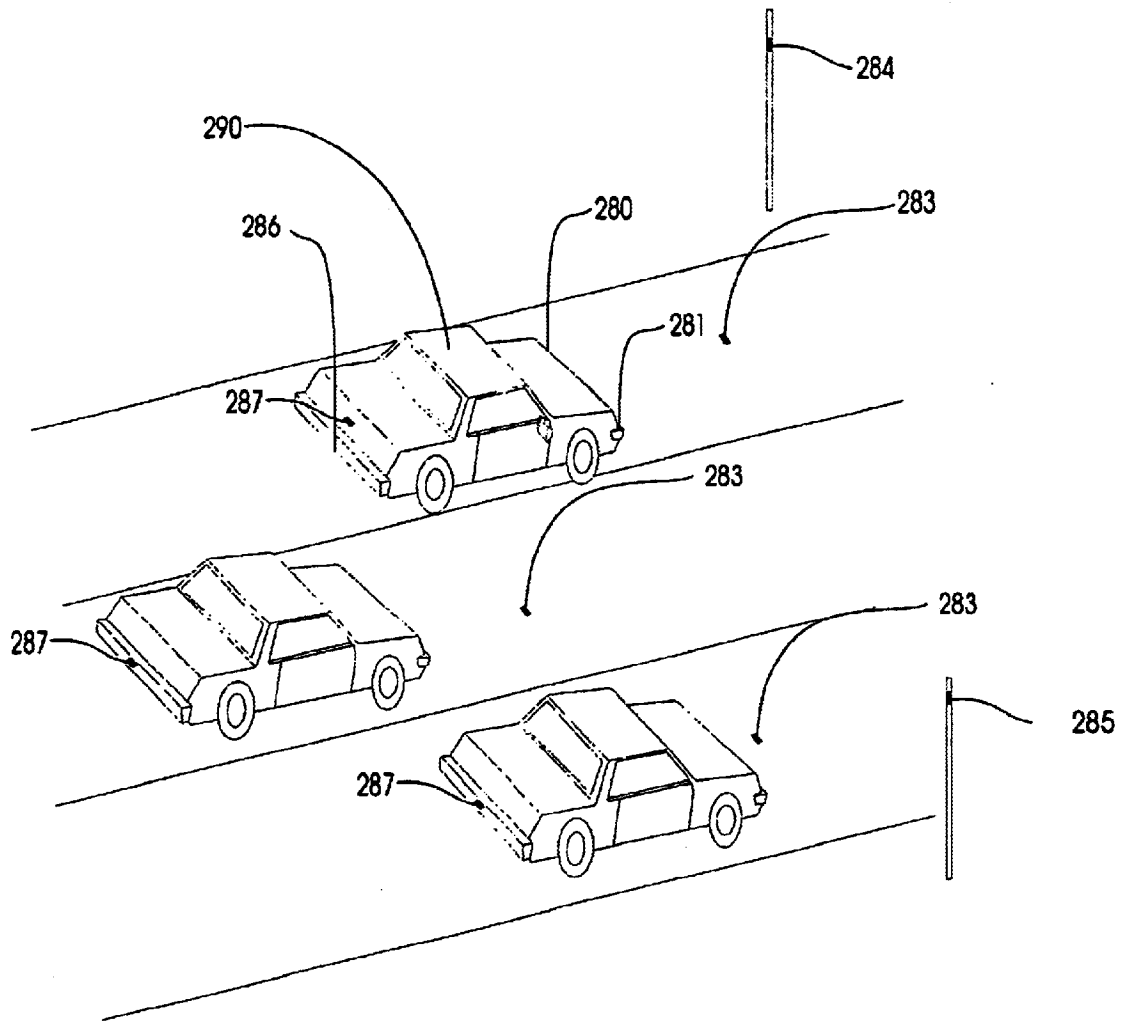


FIG. 26

U.S. Patent

Feb. 1, 2005

Sheet 30 of 39

US 6,850,824 B2

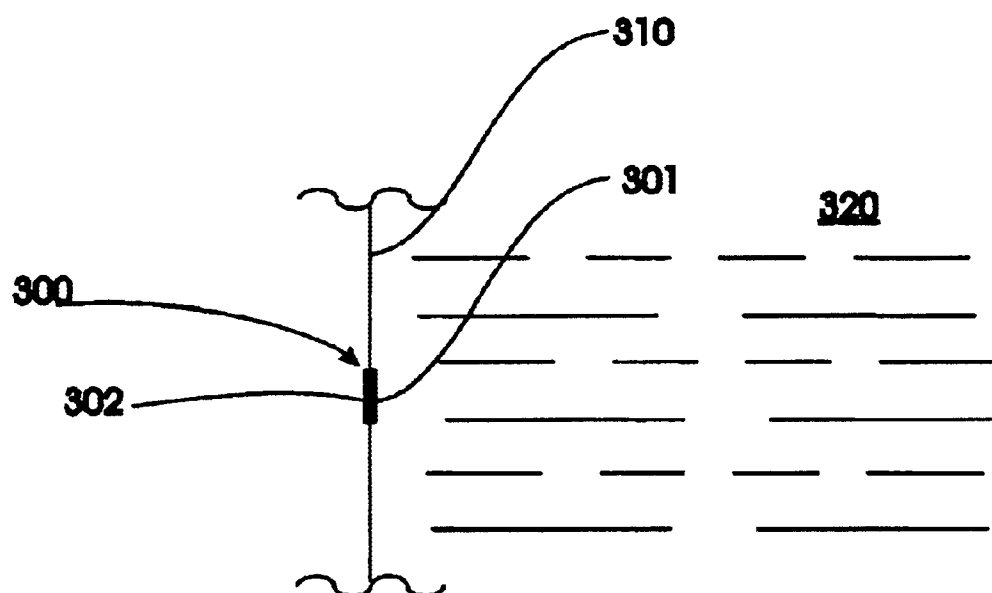


FIG. 27

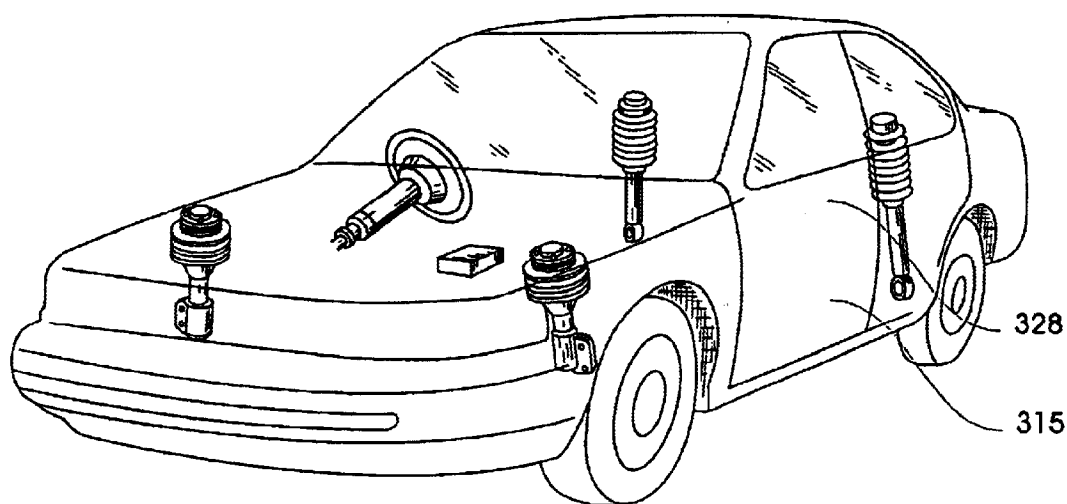


FIG. 28

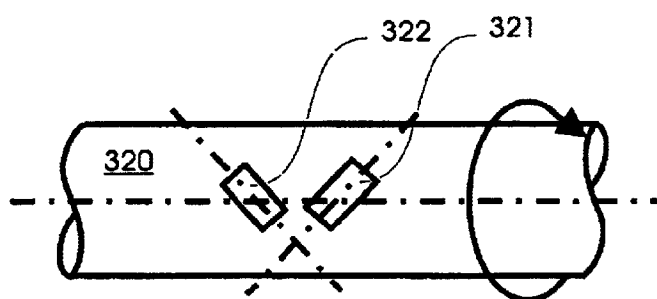


FIG. 28B

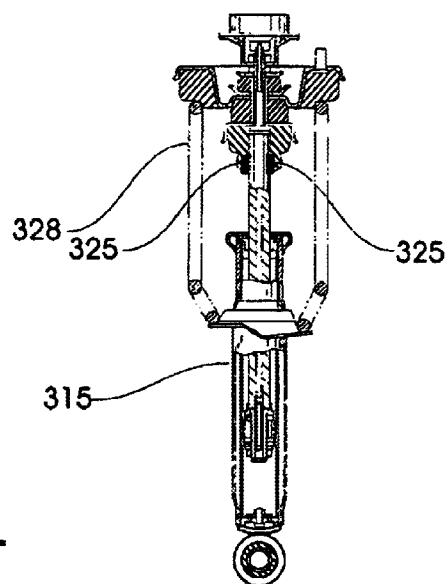


FIG. 28A

U.S. Patent

Feb. 1, 2005

Sheet 32 of 39

US 6,850,824 B2

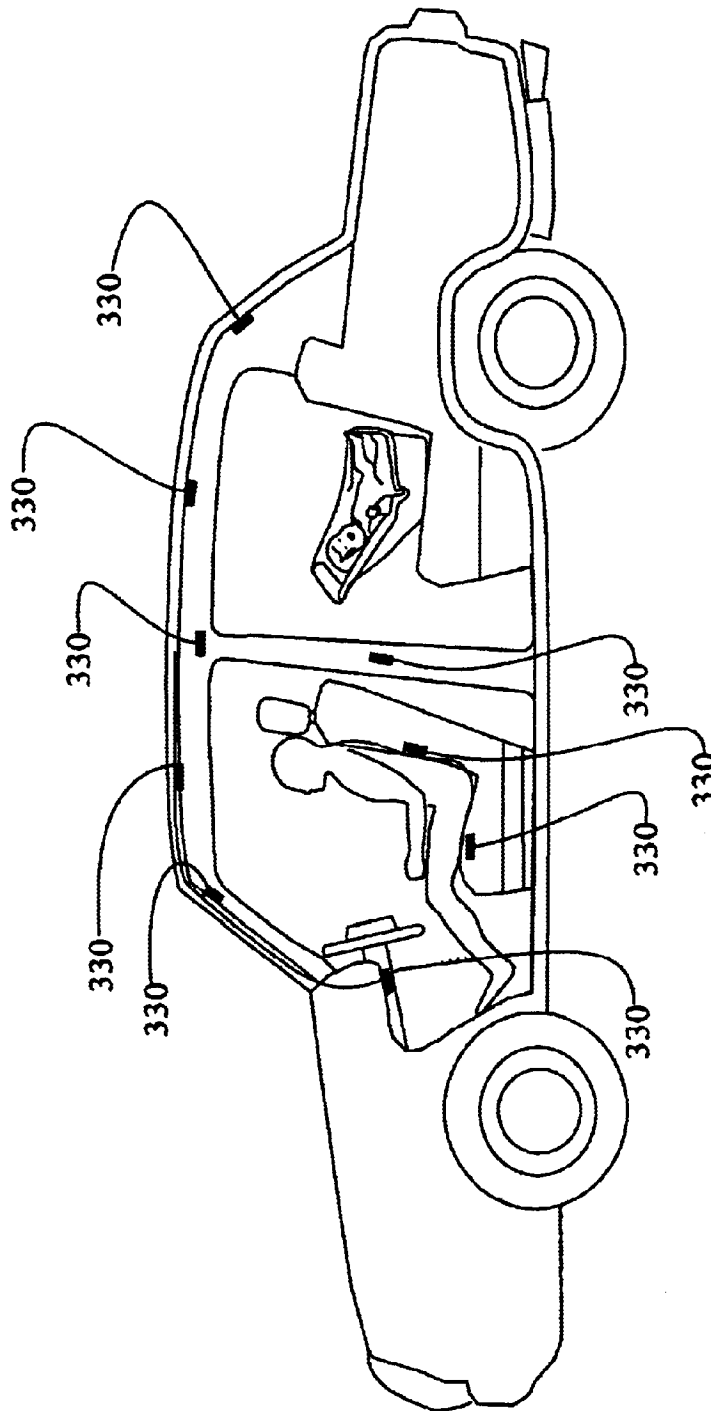


FIG. 29

U.S. Patent

Feb. 1, 2005

Sheet 33 of 39

US 6,850,824 B2

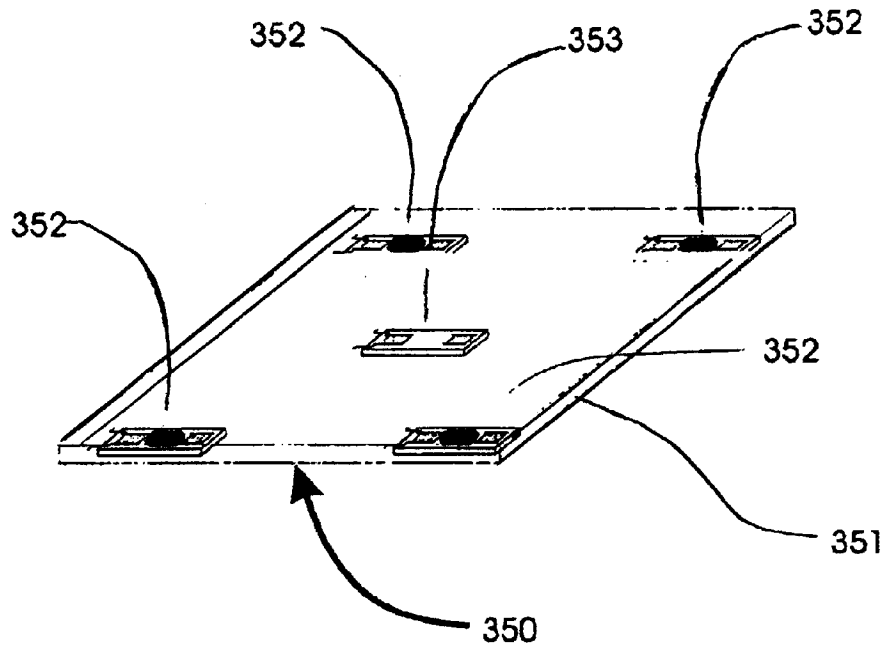


FIG. 30A

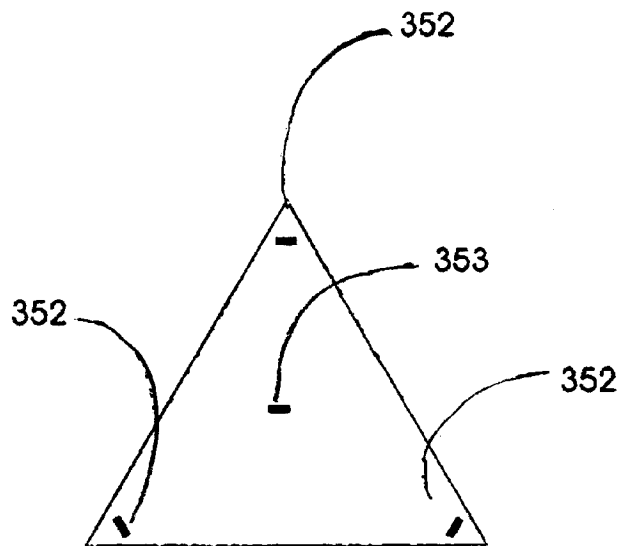


FIG. 30B

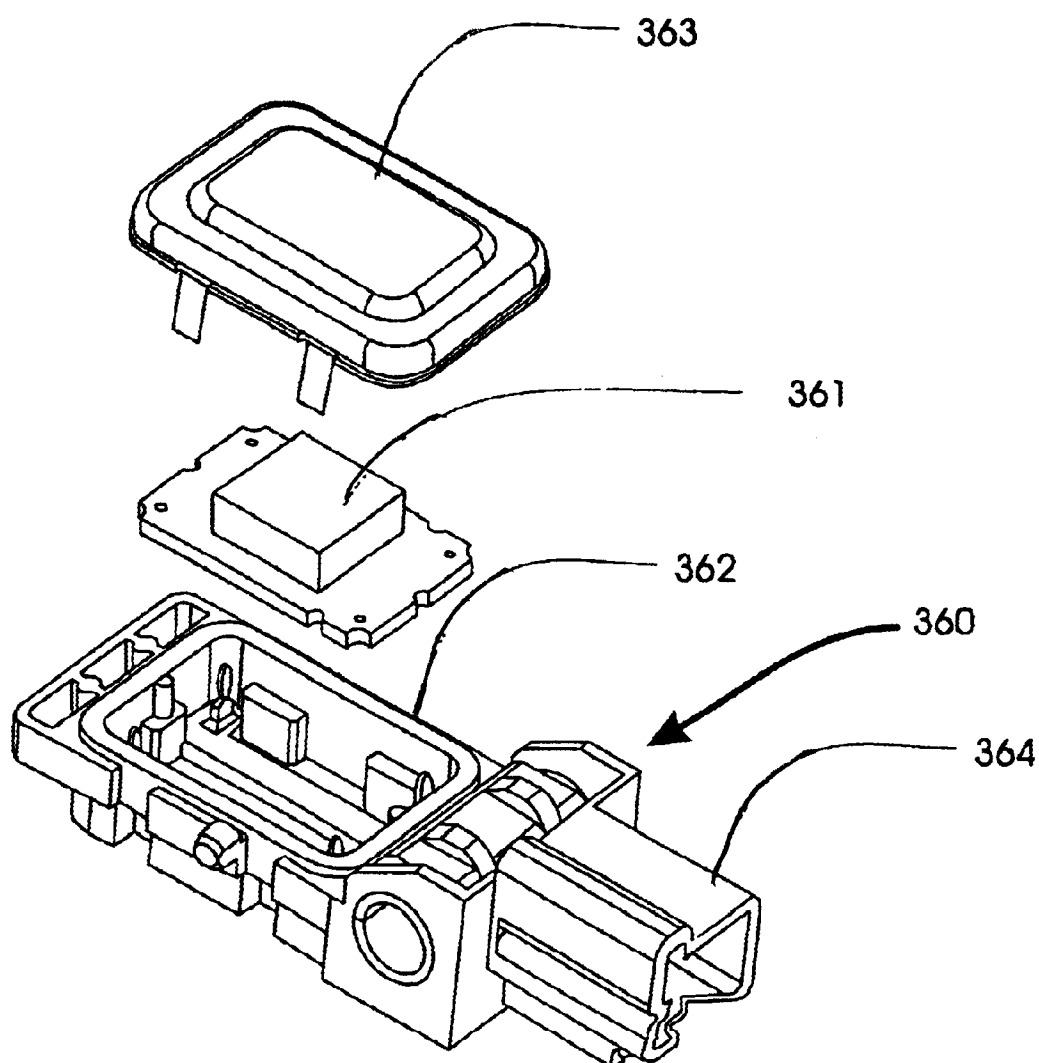


FIG. 31

U.S. Patent

Feb. 1, 2005

Sheet 35 of 39

US 6,850,824 B2

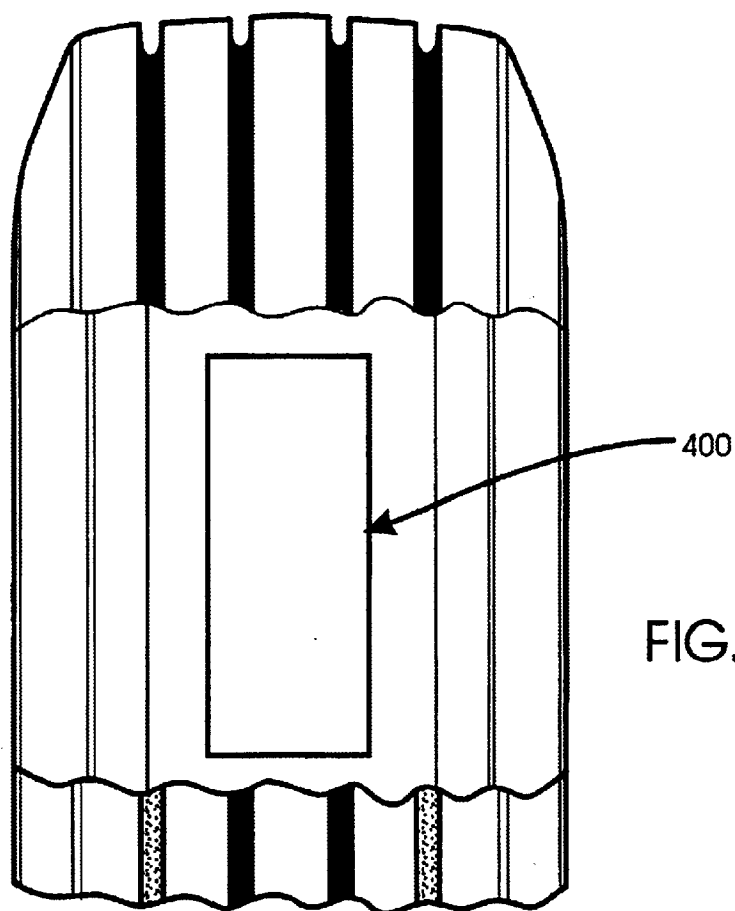


FIG. 32A

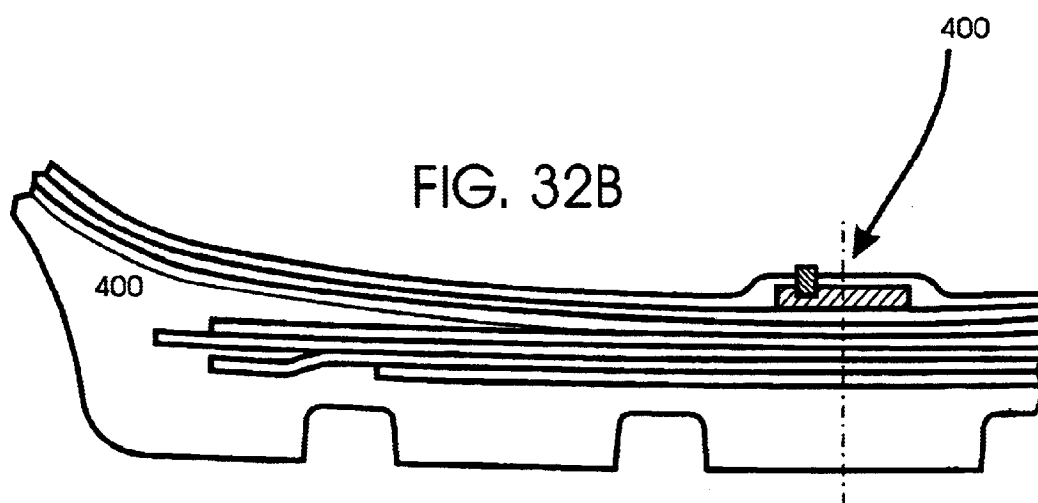


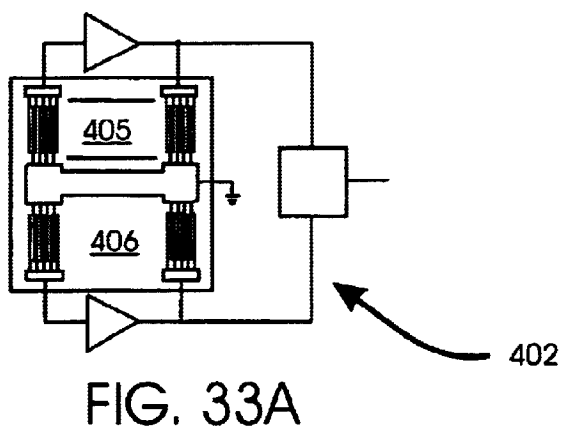
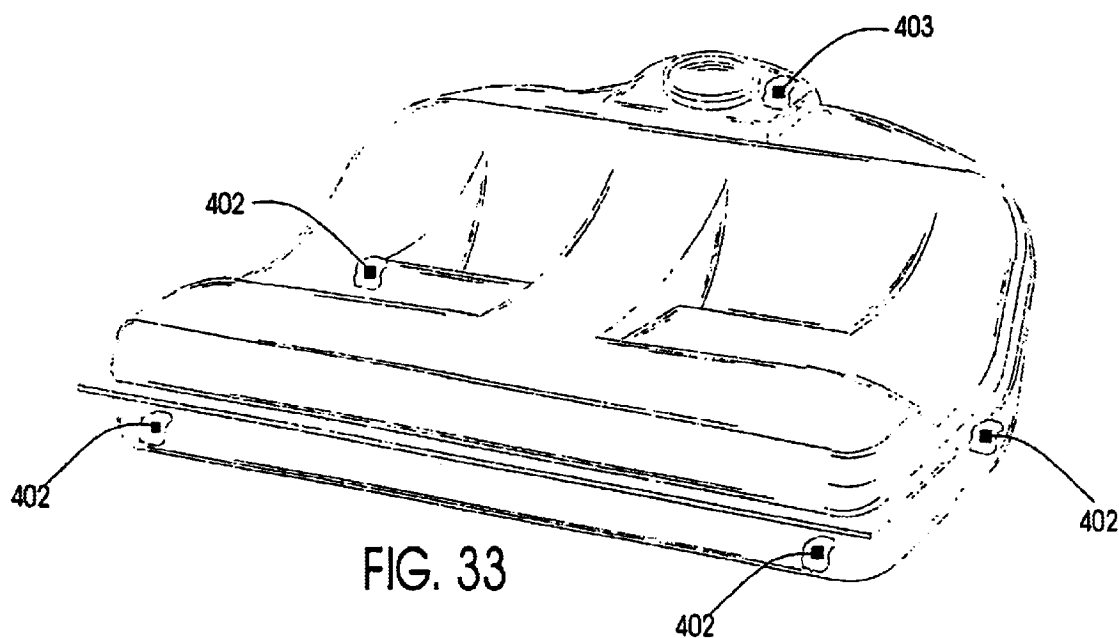
FIG. 32B

U.S. Patent

Feb. 1, 2005

Sheet 36 of 39

US 6,850,824 B2



U.S. Patent

Feb. 1, 2005

Sheet 37 of 39

US 6,850,824 B2

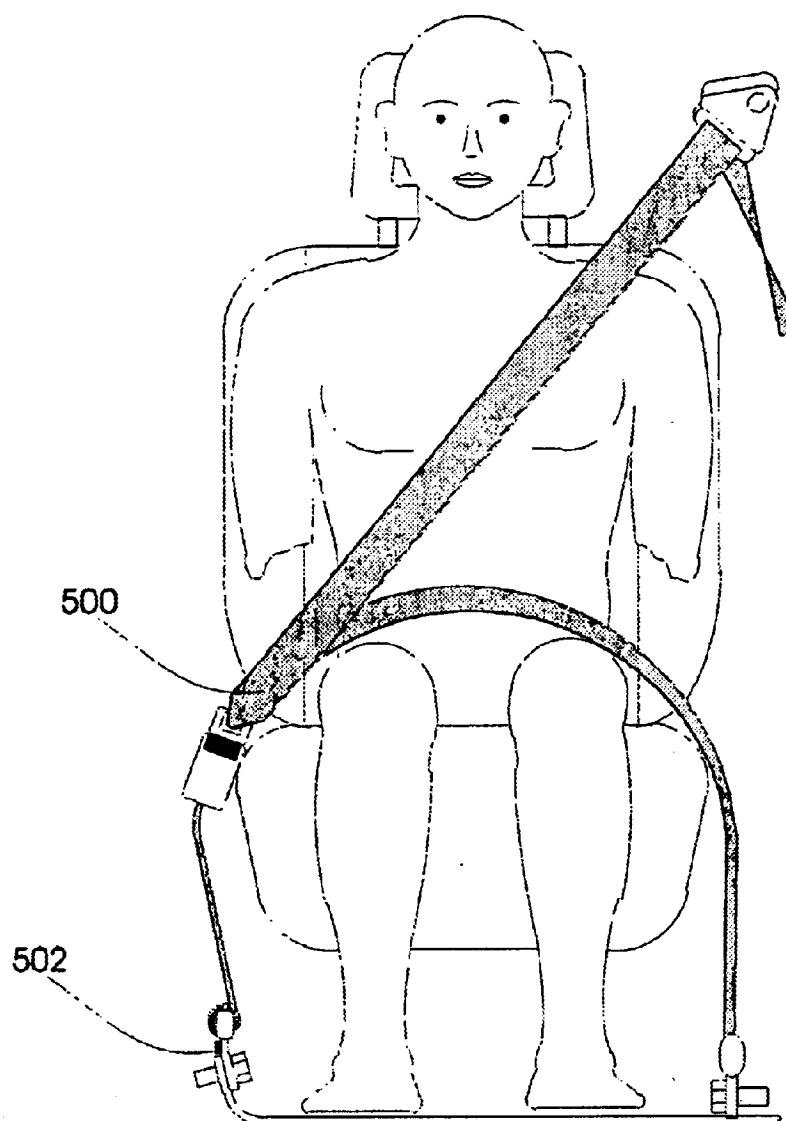


FIG. 34

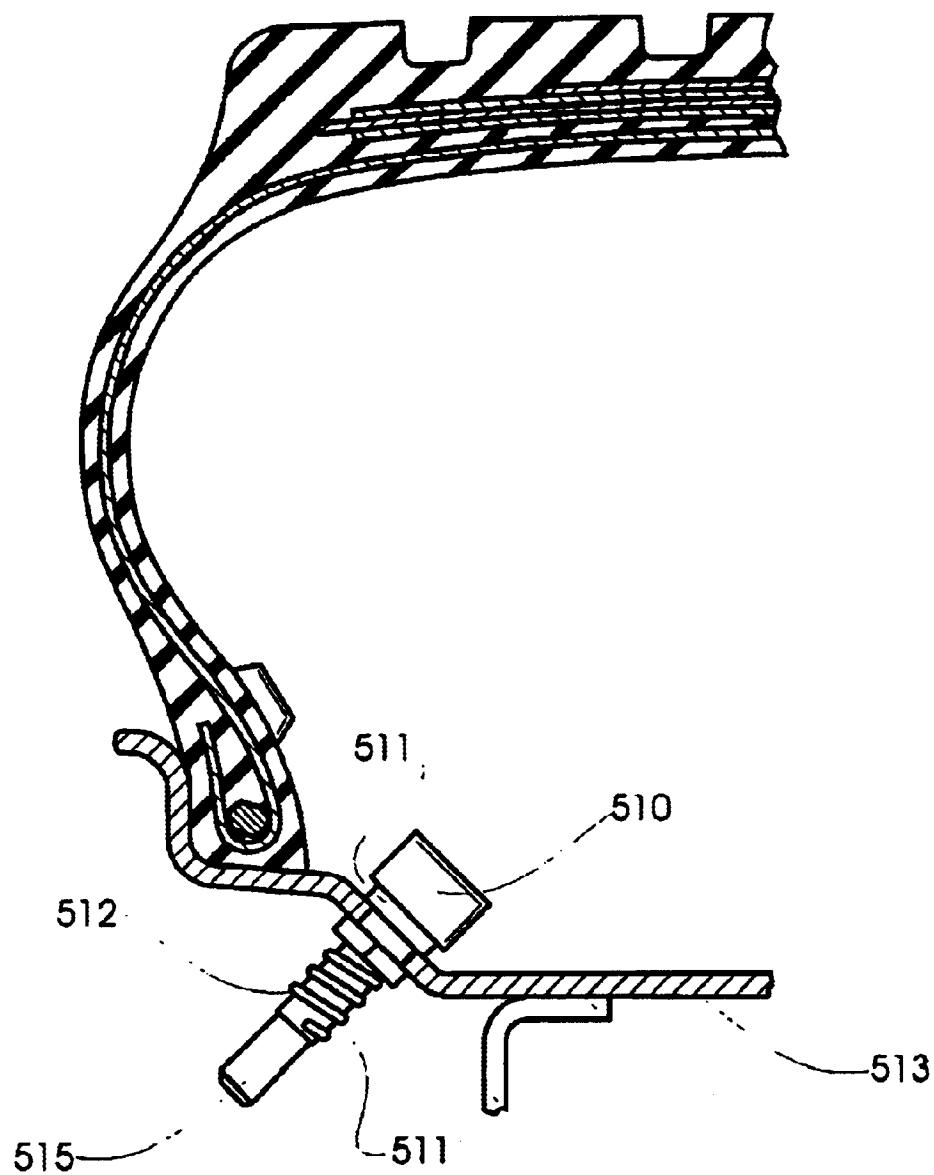


FIG. 35

U.S. Patent

Feb. 1, 2005

Sheet 39 of 39

US 6,850,824 B2

Prior Art



FIG. 36A



FIG. 36B

US 6,850,824 B2

1

METHOD AND APPARATUS FOR CONTROLLING A VEHICULAR COMPONENT

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 10/188,673 filed Jul. 3, 2002 now U.S. Pat. No. 6,738,697 which is a continuation-in-part of U.S. patent application Ser. No. 10/174,709 filed Jun. 19, 2002 now U.S. Pat. No. 6,735,506.

Said U.S. patent application Ser. No. 10/188,673 is also a continuation-in-part of U.S. patent application Ser. No. 09/753,186 filed Jan. 2, 2001, now U.S. Pat. No. 6,484,080, which is a continuation-in-part of U.S. patent application Ser. No. 09/137,918 filed Aug. 20, 1998, now U.S. Pat. No. 6,175,787, which is a continuation-in-part of U.S. patent application Ser. No. 08/476,077 filed Jun. 7, 1995, now U.S. Pat. No. 5,809,437.

Said U.S. patent application Ser. No. 10/188,673 is also a continuation-in-part of U.S. patent application Ser. No. 10/079,065 filed Feb. 19, 2002, now U.S. Pat. No. 6,662,642, which is a continuation-in-part of U.S. patent application Ser. No. 09/765,558 filed Jan. 19, 2001 now U.S. Pat. No. 6,748,747, which claims priority under 35 U.S.C. §119 (e) of U.S. provisional patent application Ser. No. 60/231,378 filed Sep. 8, 2000.

This application claims priority under 35 U.S.C. §119(e) of U.S. provisional patent application Ser. No. 60/269,415 filed Feb. 16, 2001, U.S. provisional patent application Ser. No. 60/291,511 filed May 16, 2001 and U.S. provisional patent application Ser. No. 60/304,013 filed Jul. 9, 2001 through U.S. patent application Ser. No. 10/079,065 filed Feb. 19, 2002.

All of the above-mentioned patents and applications are incorporated by reference herein in their entirety as if they had each been set forth herein in full.

FIELD OF THE INVENTION

The present invention relates to methods and apparatus for controlling an occupant restraint system in a vehicle based in part on the diagnosed state of the vehicle in an attempt to minimize injury to an occupant.

BACKGROUND OF THE INVENTION

It is now generally recognized that it is important to monitor the occupancy of a passenger compartment of a vehicle. For example, U.S. Pat. No. 5,829,782 (Breed et al.) describes a vehicle interior monitoring system that utilizes pattern recognition techniques and wave-receiving sensors to obtain information about the occupancy of the passenger compartment and uses this information to affect the operation of one or more systems in the vehicle, including an occupant restraint device, an entertainment system, a heating and air-conditioning system, a vehicle communication system, a distress notification system, a light filtering system and a security system.

Of particular interest, Breed et al. mentions that the presence of a child in a rear facing child seat placed on the right front passenger seat may be detected as this has become an industry-wide concern to prevent deployment of an occupant restraint device in these situations. The U.S. automobile industry is continually searching for an easy, economical solution, which will prevent the deployment of the passenger side airbag if a rear facing child seat is present.

2

Another important aspect disclosed in Breed et al. relates to the operation of the cellular communications system in conjunction with the vehicle interior monitoring system. Vehicles can be provided with a standard cellular phone as well as the Global Positioning System (GPS), an automobile navigation or location system with an optional connection to a manned assistance facility. In the event of an accident, the phone may automatically call 911 for emergency assistance and report the exact position of the vehicle. If the vehicle also has a system as described below for monitoring each seat location, the number and perhaps the condition of the occupants could also be reported. In that way, the emergency service (EMS) would know what equipment and how many ambulances to send to the accident site. Moreover, a communication channel can be opened between the vehicle and a monitoring facility/emergency response facility or personnel to determine how badly people are injured, the number of occupants in the vehicle, and to enable directions to be provided to the occupant(s) of the vehicle to assist in any necessary first aid prior to arrival of the emergency assistance personnel.

Communications between a vehicle and a remote assistance facility are also important for the purpose of diagnosing problems with the vehicle and forecasting problems with the vehicle, called prognostics. Motor vehicles contain complex mechanical systems that are monitored and regulated by computer systems such as electronic control units (ECUs) and the like. Such ECUs monitor various components of the vehicle including engine performance, carburation, speed/acceleration control, transmission, exhaust gas recirculation (EGR), braking systems, etc. However, vehicles perform such monitoring typically only for the vehicle driver and without communication of any impending results, problems and/or vehicle malfunction to a remote site for troubleshooting, diagnosis or tracking for data mining.

In the past, systems that provide for remote monitoring did not provide for automated analysis and communication of problems or potential problems and recommendations to the driver. As a result, the vehicle driver or user is often left stranded, or irreparable damage occurs to the vehicle as a result of neglect or driving the vehicle without the user knowing the vehicle is malfunctioning until it is too late, such as low oil level and a malfunctioning warning light, fan belt about to fail, failing radiator hose etc.

In this regard, U.S. Pat. No. 5,400,018 (Scholl et al.) describes a system for relaying raw sensor output from an off road work site relating to the status of a vehicle to a remote location over a communications data link. The information consists of fault codes generated by sensors and electronic control modules indicating that a failure has occurred rather than forecasting a failure. The vehicle does not include a system for performing diagnosis. Rather, the raw sensor data is processed at an off-vehicle location in order to arrive at a diagnosis of the vehicle's operating condition. Bi-directional communications are described in that a request for additional information can be sent to the vehicle from the remote location with the vehicle responding and providing the requested information but no such communication takes place with the vehicle operator and not of an operator of a vehicle traveling on a road. Also, Scholl et al. does not teach the diagnostics of the problem or potential problem on the vehicle itself nor does it teach the automatic diagnostics or any prognostics. In Scholl et al. the determination of the problem occurs at the remote site by human technicians.

U.S. Pat. No. 5,754,965 (Hagenbuch) describes an apparatus for diagnosing the state of health of a vehicle and providing the operator of the vehicle with a substantially

US 6,850,824 B2

3

real-time indication of the efficiency of the vehicle in performing as assigned task with respect to a predetermined goal. A processor in the vehicle monitors sensors that provide information regarding the state of health of the vehicle and the amount of work the vehicle has done. The processor records information that describes events leading up to the occurrence of an anomaly for later analysis. The sensors are also used to prompt the operator to operate the vehicle at optimum efficiency.

U.S. Pat. No. 5,955,942 (Slifkin et al.) describes a method for monitoring events in vehicles in which electrical outputs representative of events in the vehicle are produced, the characteristics of one event are compared with the characteristics of other events accumulated over a given period of time and departures or variations of a given extent from the other characteristics are determined as an indication of a significant event. A warning is sent in response to the indication, including the position of the vehicle as determined by a global positioning system on the vehicle. For example, for use with a railroad car, a microprocessor responds to outputs of an accelerometer by comparing acceleration characteristics of one impact with accumulated acceleration characteristics of other impacts and determines departures of a given magnitude from the other characteristics as a failure indication which gives rise of a warning.

Every automobile driver fears that his or her vehicle will breakdown at some unfortunate time, e.g., when he or she is traveling at night, during rush hour, or on a long trip away from home. To help alleviate that fear, certain luxury automobile manufacturers provide roadside service in the event of a breakdown. Nevertheless, unless the vehicle is equipped with OnStar® or an equivalent service, the vehicle driver must still be able to get to a telephone to call for service. It is also a fact that many people purchase a new automobile out of fear of a breakdown with their current vehicle. This invention is primarily concerned with preventing breakdowns and with minimizing maintenance costs by predicting component failure that would lead to such a breakdown before it occurs.

When a vehicle component begins to fail, the repair cost is frequently minimal if the impending failure of the component is caught early, but increases as the repair is delayed. Sometimes if a component in need of repair is not caught in a timely manner, the component, and particularly the impending failure thereof, can cause other components of the vehicle to deteriorate. One example is where the water pump fails gradually until the vehicle overheats and blows a head gasket. It is desirable, therefore, to determine that a vehicle component is about to fail as early as possible so as to minimize the probability of a breakdown and the resulting repair costs.

There are various gages on an automobile which alert the driver to various vehicle problems. For example, if the oil pressure drops below some predetermined level, the driver is warned to stop his vehicle immediately. Similarly, if the coolant temperature exceeds some predetermined value, the driver is also warned to take immediate corrective action. In these cases, the warning often comes too late as most vehicle gages alert the driver after he or she can conveniently solve the problem. Thus, what is needed is a component failure warning system that alerts the driver to the impending failure of a component sufficiently in advance of the time when the problem gets to a catastrophic point.

Some astute drivers can sense changes in the performance of their vehicle and correctly diagnose that a problem with a component is about to occur. Other drivers can sense that

4

their vehicle is performing differently but they don't know why or when a component will fail or how serious that failure will be, or possibly even what specific component is the cause of the difference in performance. The invention disclosed herein will, in most cases, solve this problem by predicting component failures in time to permit maintenance and thus prevent vehicle breakdowns.

Presently, automobile sensors in use are based on specific predetermined or set levels, such as the coolant temperature or oil pressure, whereby an increase above the set level or a decrease below the set level will activate the sensor, rather than being based on changes in this level over time. The rate at which coolant heats up, for example, can be an important clue that some component in the cooling system is about to fail. There are no systems currently on automobiles to monitor the numerous vehicle components over time and to compare component performance with normal performance. Nowhere in the vehicle is the vibration signal of a normally operating front wheel stored, for example, or for that matter, any normal signal from any other vehicle component. Additionally, there is no system currently existing on a vehicle to look for erratic behavior of a vehicle component and to warn the driver or the dealer that a component is misbehaving and is therefore likely to fail in the very near future.

Sometimes, when a component fails, a catastrophic accident results. In the Firestone tire case, for example, over 100 people were killed when a tire of a Ford Explorer blew out which caused the Ford Explorer to rollover. Similarly, other component failures can lead to loss of control of the vehicle and a subsequent accident. It is thus very important to accurately forecast that such an event will take place but furthermore, for those cases where the event takes place suddenly without warning, it is also important to diagnose the state of the entire vehicle, which in some cases can lead to automatic corrective action to prevent unstable vehicle motion or rollovers resulting in an accident. Finally, an accurate diagnostic system for the entire vehicle can determine much more accurately the severity of an automobile crash once it has begun by knowing where the accident is taking place on the vehicle (e.g., the part of or location on the vehicle which is being impacted by an object) and what is colliding with the vehicle based on a knowledge of the force deflection characteristics of the vehicle at that location. Therefore, in addition to a component diagnostic, the teachings of this invention also provide a diagnostic system for the entire vehicle prior to and during accidents. In particular, this invention is concerned with the simultaneous monitoring of multiple sensors on the vehicle so that the best possible determination of the state of the vehicle can be determined. Current crash sensors operate independently or at most one sensor may influence the threshold at which another sensor triggers a deployable restraint. In the teachings of this invention, two or more sensors, frequently accelerometers, are monitored simultaneously and the combination of the outputs of these multiple sensors are combined continuously in making the crash severity analysis.

Marko et al. (U.S. Pat. No. 5,041,976) is directed to a diagnostic system using pattern recognition for electronic automotive control systems and particularly for diagnosing faults in the engine of a motor vehicle after they have occurred. For example, Marko et al. is interested in determining cylinder specific faults after the cylinder is operating abnormally. More specifically, Marko et al. is directed to detecting a fault in a vehicular electromechanical system indirectly, i.e., by means of the measurement of parameters of sensors which are affected by that system, and after that

US 6,850,824 B2

5

fault has already manifested itself in the system. In order to form the fault detecting system, the parameters from these sensors are input to a pattern recognition system for training thereof. Then, known faults are introduced and the parameters from the sensors are input into the pattern recognition system with an indicia of the known fault. Thus, during subsequent operation, the pattern recognition system can determine the fault of the electromechanical system based on the parameters of the sensors, assuming that the fault was "trained" into the pattern recognition system and has already occurred.

When the electromechanical system is an engine, the parameters input into the pattern recognition system for training thereof, and used for fault detection during operation, all relate to the engine. (If the electromechanical system is other than the engine, then the parameters input into the pattern recognition system would relate to that system.) In other words, each parameter will be affected by the operation of the engine and depend thereon and changes in the operation of the engine will alter the parameter, e.g., the manifold absolute pressure is an indication of the airflow into the engine. In this case, the signal from the manifold absolute pressure sensor may be indicative of a fault in the intake of air into the engine, e.g., the engine is drawing in too much or too little air, and is thus affected by the operation of the engine. Similarly, the mass air flow is the airflow into the engine and is an alternative to the manifold absolute pressure. It is thus a parameter that is directly associated with, related to and dependent on the engine. The exhaust gas oxygen sensor is also affected by the operation of the engine, and thus directly associated therewith, since during normal operation, the mixture of the exhaust gas is neither rich or lean whereas during abnormal engine operation, the sensor will detect an abrupt change indicative of the mixture being too rich or too lean.

Thus, the system of Marko et al. is based on the measurement of sensors which affect or are affected by, i.e., are directly associated with, the operation of the electromechanical system for which faults are to be detected. However, the system of Marko et al. does not detect faults in the sensors that are conducting the measurements, e.g., a fault in the exhaust gas oxygen sensor, or faults that are only developing but have not yet manifested themselves or faults in other systems. Rather, the sensors are used to detect a fault in the system after it has occurred.

Asami et al. (U.S. Pat. No. 4,817,418) is directed to a failure diagnosis system for a vehicle including a failure display means for displaying failure information to a driver. This system only reports failures after they have occurred and does not predict them.

Tiernan et al. (U.S. Pat. No. 5,313,407) is directed, inter alia, to a system for providing an exhaust active noise control system, i.e., an electronic muffler system, including an input microphone 60 which senses exhaust noise at a first location 61 in an exhaust duct 58. An engine has exhaust manifolds 56,57 feeding exhaust air to the exhaust duct 58. The exhaust noise sensed by the microphone 60 is processed to obtain an output from an output speaker 65 arranged downstream of the input microphone 61 in the exhaust path in order to cancel the noise in the exhaust duct 58.

Haramaty et al. (U.S. Pat. No. 5,406,502) describes a system that monitors a machine in a factory and notifies maintenance personnel remote from the machine (not the machine operator) that maintenance should be scheduled at a time when the machine is not in use. Haramaty et al. does not expressly relate to vehicular applications.

6

NASA Technical Support Package MFS-26529 "Engine Monitoring Based on Normalized Vibration Spectra", describes a technique for diagnosing engine health using a neural network based system and is incorporated by reference herein in its entirety.

A paper "Using acoustic emission signals for monitoring of production processes" by H. K. Tonshoff et al. also provides a good description of how acoustic signals can be used to predict the state of machine tools and is incorporated by reference herein in its entirety.

Based on the monitoring of vehicular components, systems and subsystems as well as to the measurement of physical and chemical characteristics relating to the vehicle or its components, systems and subsystems, it becomes possible to control and/or affect one or more vehicular system.

An important component or system which is monitored is the tires as failure of one or more of the tires can often lead to a fatal accident. Indeed, tire monitoring is extremely important since NHTSA (National Highway Traffic Safety Administration) has recently linked 148 deaths and more than 525 injuries in the United States to separations, blow-outs and other tread problems in Firestone's ATX, ATX II and Wilderness AT tires, 5 million of which were recalled in 2000. Many of the tires were standard equipment on the Ford Explorer. Ford recommends that the Firestone tires on the Explorer sport utility vehicle be inflated to 26 psi, while Firestone recommends 30 psi. It is surprising that a tire can go from a safe condition to an unsafe condition based on an under inflation of 4 psi.

Recent studies in the United States conducted by the Society of Automotive Engineers show that low tire pressure causes about 260,000 accidents annually. Another finding is that about 75% of tire failures each year are preceded by slow air leaks or inadequate tire inflation. Nissan, for example, warns that incorrect tire pressures can compromise the stability and overall handling of a vehicle and can contribute to an accident. Additionally, most non-crash auto fatalities occur while drivers are changing flat tires. Thus, tire failures are clearly a serious automobile safety problem that requires a solution.

About 16% of all car accidents are a result of incorrect tire pressure. Thus, effective pressure and wear monitoring is extremely important. Motor Trend magazine stated that one of the most overlooked maintenance areas on a car is tire pressure. An estimated 40 to 80 percent of all vehicles on the road are operating with under-inflated tires. When under-inflated, a tire tends to flex its sidewall more, increasing its rolling resistance which decreases fuel economy. The extra flex also creates excessive heat in the tire that can shorten its service life.

The Society of Automotive Engineers reports that about 87 percent of all flat tires have a history of underinflation. About 85% of pressure loss incidents are slow punctures caused either by small-diameter objects trapped in the tire or by larger diameter nails. The leak will be minor as long as the nail is trapped. If the nail comes out, pressure can decrease rapidly. Incidents of sudden pressure loss are potentially the most dangerous for drivers and account for about 15% of all cases.

A properly inflated tire loses approximately 1 psi per month. A defective tire can lose pressure at a more rapid rate. About 35 percent of the recalled Bridgestone tires had improper repairs.

Research from a variety of sources suggests that under-inflation can be significant to both fuel economy and tire life.

US 6,850,824 B2

7

Industry experts have determined that tires under-inflated by a mere 10% wear out about 15% faster. An average driver with an average set of tires can drive an extra 5,000 to 7,000 miles before buying new tires by keeping the tire properly inflated.

The American Automobile Association has determined that under inflated tires cut a vehicle's fuel economy by as much as 2% per psi below the recommended level. If each of a car's tires is supposed to have a pressure of 30 psi and instead has a pressure of 25 psi, the car's fuel efficiency drops by about 10%. Depending on the vehicle and miles driven that could cost from \$100 to \$500 a year.

The ability to control a vehicle is strongly influenced by tire pressure. When the tire pressure is kept at proper levels, optimum vehicle braking, steering, handling and stability are accomplished. Low tire pressure can also lead to damage to both the tires and wheels.

A Michelin study revealed that the average driver doesn't recognize a low tire until it's 14 psi too low. One of the reasons is that today's radial tire is hard to judge visually because the sidewall flexes even when properly inflated.

Despite all the recent press about keeping tires properly inflated, new research shows that most drivers do not know the correct inflation pressure. In a recent survey, only 45 percent of respondents knew where to look to find the correct pressure, even though 78 percent thought they knew. Twenty-seven percent incorrectly believed the sidewall of the tire carries the correct information and did not know that the sidewall only indicates the maximum pressure for the tire, not the optimum pressure for the vehicle. In another survey, about 60% of the respondents reported that they check tire pressure but only before going on a long trip. The National Highway Traffic Safety Administration estimates that at least one out of every five tires is not properly inflated.

The problem is exacerbated with the new run-flat tires where a driver may not be aware that a tire is flat until it is destroyed. Run-flat tires can be operated at air pressures below normal for a limited distance and at a restricted speed (125 miles at a maximum of 55 mph). The driver must therefore be warned of changes in the condition of the tires so that she can adapt her driving to the changed conditions.

One solution to this problem is to continuously monitor the pressure and perhaps the temperature in the tire. Pressure loss can be automatically detected in two ways: by directly measuring air pressure within the tire or by indirect tire rotation methods. Various indirect methods are based on the number of revolutions each tire makes over an extended period of time through the ABS system and others are based on monitoring the frequency changes in the sound emitted by the tire. In the direct detection case, a sensor is mounted into each wheel or tire assembly, each with its own identity. An on-board computer collects the signals, processes and displays the data and triggers a warning signal in the case of pressure loss.

Under-inflation isn't the only cause of sudden tire failure. A variety of mechanical problems including a bad wheel bearing or a "dragging" brake can cause the tire to heat up and fail. In addition, as may have been a contributing factor in the Firestone case, substandard materials can lead to intra-tire friction and a buildup of heat. The use of re-capped truck tires is another example of heat caused failure as a result by intra-tire friction. An overheated tire can fail suddenly without warning.

As discussed in more detail below, tire monitors, such as those disclosed below, permit the driver to check the vehicle tire pressures from inside the vehicle.

8

The *Transportation Recall Enhancement, Accountability and Documentation Act*, (H.R. 5164, or Public Law No. 106-414) known as the TREAD Act, was signed by President Clinton on Nov. 1, 2000. Section 12, TIRE PRESSURE WARNING, states that: "Not later than one year after the date of enactment of this Act, the Secretary of Transportation, acting through the National Highway Traffic Safety Administration, shall complete a rulemaking for a regulation to require a warning system in a motor vehicle to indicate to the operator when a tire is significantly under-inflated. Such requirement shall become effective not later than 2 years after the date of the completion of such rulemaking." Thus, it is expected that a rule requiring continuous tire monitoring will take effect for the 2004 model year.

This law will dominate the first generation of such systems as automobile manufacturers move to satisfy the requirement. In subsequent years, more sophisticated systems that in addition to pressure will monitor temperature, tire footprint, wear, vibration, etc. Although the Act requires that the tire pressure be monitored, it is believed by the inventors that other parameters are as important as the tire pressure or even more important than the tire pressure as described in more detail below.

Consumers are also in favor of tire monitors. Johnson Controls' market research showed that about 80 percent of consumers believe a low tire pressure warning system is an important or extremely important vehicle feature. Thus, as with other safety products such as airbags, competition to meet customer demands will soon drive this market.

Although, as with most other safety products, the initial introductions will be in the United States, speed limits in the United States and Canada are sufficiently low that tire pressure is not as critical an issue as in Europe, for example, where the drivers often drive much faster.

The advent of microelectromechanical (MEMS) pressure sensors, especially those based on surface acoustical wave (SAW) technology, has now made the wireless and powerless monitoring of tire pressure feasible. This is the basis of the tire pressure monitors described below. According to a Frost and Sullivan report on the U.S. Micromechanical Systems (MEMS) market (June 1997): "A MEMS tire pressure sensor represents one of the most profound opportunities for MEMS in the automotive sector."

There are many wireless tire temperature and pressure monitoring systems disclosed in the prior art patents such as for example, U.S. Pat. Nos. 4,295,102, 4,296,347, 4,317,372, 4,534,223, 5,289,160, 5,612,671, 5,661,651, 5,853,020 and 5,987,980 and International Publication No. WO 01/07271(A1), all of which are illustrative of the state of the art of tire monitoring and are incorporated by reference herein.

Devices for measuring the pressure and/or temperature within a vehicle tire directly can be categorized as those containing electronic circuits and a power supply within the tire, those which contain electronic circuits and derive the power to operate these circuits either inductively, from a generator or through radio frequency radiation, and those that do not contain electronic circuits and receive their operating power only from received radio frequency radiation. For the reasons discussed above, the discussion herein is mainly concerned with the latter category. This category contains devices that operate on the principles of surface acoustic waves (SAW) and the disclosure below is concerned primarily with such SAW devices.

International Publication No. WO 01/07271 describes a tire pressure sensor that replaces the valve and valve stem in a tire.

US 6,850,824 B2

9

U.S. Pat. No. 5,231,827 contains a good description and background of the tire-monitoring problem. The device disclosed, however, contains a battery and electronics and is not a SAW device. Similarly, the device described in U.S. Pat. No. 5,285,189 contains a battery as do the devices described in U.S. Pat. Nos. 5,335,540 and 5,559,484. U.S. Pat. No. 5,945,908 applies to a stationary tire monitoring system and does not use SAW devices.

One of the first significant SAW sensor patents is U.S. Pat. No. 4,534,223. This patent describes the use of SAW devices for measuring pressure and also a variety of methods for temperature compensation but does not mention wireless transmission.

U.S. Pat. No. 5,987,980 describes a tire valve assembly using a SAW pressure transducer in conjunction with a sealed cavity. This patent does disclose wireless transmission. The assembly includes a power supply and thus this also distinguishes it from a preferred system of this invention. It is not a SAW system and thus the antenna for interrogating the device in this design must be within one meter, which is closer than needed for a preferred device of this invention.

U.S. Pat. No. 5,698,786 relates to the sensors and is primarily concerned with the design of electronic circuits in an interrogator. U.S. Pat. No. 5,700,952 also describes circuitry for use in the interrogator to be used with SAW devices. In neither of these patents is the concept of using a SAW device in a wireless tire pressure monitoring system described. These patents also do not describe including an identification code with the temperature and/or pressure measurements in the sensors and devices.

U.S. Pat. No. 5,804,729 describes circuitry for use with an interrogator in order to obtain more precise measurements of the changes in the delay caused by the physical or chemical property being measured by the SAW device. Similar comments apply to U.S. Pat. No. 5,831,167. Other related prior art includes U.S. Pat. No. 4,895,017.

Other patents disclose the placement of an electronic device in the sidewall or opposite the tread of a tire but they do not disclose either an accelerometer or a surface acoustic wave device. In most cases, the disclosed system has a battery and electronic circuits.

One method of measuring pressure that is applicable to this invention is disclosed in V. V. Varadan, Y. R. Roh and V. K. Varadan "Local/Global SAW Sensors for Turbulence", IEEE 1989 Ultrasonics Symposium p. 591-594 makes use of a polyvinylidene fluoride (PVDF) piezoelectric film to measure pressure. Mention is made in this article that other piezoelectric materials can also be used. Experimental results are given where the height of a column of oil is measured based on the pressure measured by the piezoelectric film used as a SAW device. In particular, the speed of the surface acoustic wave is determined by the pressure exerted by the oil on the SAW device. For the purposes of the instant invention, air pressure can also be measured in a similar manner by first placing a thin layer of a rubber material onto the surface of the SAW device which serves as a coupling agent from the air pressure to the SAW surface. In this manner, the absolute pressure of a tire, for example, can be measured without the need for a diaphragm and reference pressure greatly simplifying the pressure measurement. Other examples of the use of PVDF film as a pressure transducer can be found in U.S. Pat. Nos. 4,577,510 and 5,341,687, which are incorporated by reference herein, although they are not used as SAW devices.

The following U.S. patents provide relevant information to this invention, and to the extent necessary, all of them are

10

incorporated by reference herein: U.S. Pat. Nos. 4,361,026, 4,620,191, 4,7033,27, 4,724,443, 4,725,841, 4,734,698, 5,691,698, 5,841,214, 6,060,815, 6,107,910, 6,114,971, 6,144,332.

In recent years, SAW devices have been used as sensors in a broad variety of applications. Compared with sensors utilizing alternative technologies, SAW sensors possess outstanding properties, such as high sensitivity, high resolution, and ease of manufacturing by microelectronic technologies. However, the most attractive feature of SAW sensors is that they can be interrogated wirelessly.

DEFINITIONS

As used herein, a diagnosis of the "state of the vehicle" means a diagnosis of the condition of the vehicle with respect to its stability and proper running and operating condition. Thus, the state of the vehicle could be normal when the vehicle is operating properly on a highway or abnormal when, for example, the vehicle is experiencing excessive angular inclination (e.g., two wheels are off the ground and the vehicle is about to rollover), the vehicle is experiencing a crash, the vehicle is skidding, and other similar situations. A diagnosis of the state of the vehicle could also be an indication that one of the parts of the vehicle, e.g., a component, system or subsystem, is operating abnormally.

As used herein, an "occupant restraint device" includes any type of device which is deployable in the event of a crash involving the vehicle for the purpose of protecting an occupant from the effects of the crash and/or minimizing the potential injury to the occupant. Occupant restraint devices thus include frontal airbags, side airbags, seatbelt tensioners, knee bolsters, side curtain airbags, externally deployable airbags and the like.

As used herein, a "part" of the vehicle includes any component, sensor, system or subsystem of the vehicle such as the steering system, braking system, throttle system, navigation system, airbag system, seatbelt retractor, air bag inflation valve, air bag inflation controller and airbag vent valve, as well as those listed below in the definitions of "component" and "sensor".

As used herein, a "sensor system" includes any of the sensors listed below in the definition of "sensor" as well as any type of component or assembly of components which detect, sense or measure something.

The term "gage" as used herein interchangeably with the terms "sensor" and "sensing device".

Preferred embodiments of the invention are described below and unless specifically noted, it is the applicants' intention that the words and phrases in the specification and claims be given the ordinary and accustomed meaning to those of ordinary skill in the applicable art(s). If the applicant intends any other meaning, he will specifically state he is applying a special meaning to a word or phrase.

Likewise, applicants' use of the word "function" here is not intended to indicate that the applicants seek to invoke the special provisions of 35 U.S.C. § 112, sixth paragraph, to define their invention. To the contrary, if applicants wish to invoke the provisions of 35 U.S.C. § 112, sixth paragraph, to define their invention, they will specifically set forth in the claims the phrases "means for" or "step for" and a function, without also reciting in that phrase any structure, material or act in support of the function. Moreover, even if applicants invoke the provisions of 35 U.S.C. § 112, sixth paragraph, to define their invention, it is the applicants' intention that their inventions not be limited to the specific structure, material or

US 6,850,824 B2

11

acts that are described in the preferred embodiments herein. Rather, if applicants claim their inventions by specifically invoking the provisions of 35 U.S.C. §112, sixth paragraph, it is nonetheless their intention to cover and include any and all structure, materials or acts that perform the claimed function, along with any and all known or later developed equivalent structures, materials or acts for performing the claimed function.

OBJECTS OF THE INVENTION

A primary object of the invention to provide new and improved methods and apparatus for controlling an occupant restraint device based on information provided by various sensors.

It is another object of the present invention to provide a new and improved method and system for diagnosing components in a vehicle and the operating status of the vehicle and alerting the vehicle's dealer, or another repair facility, via a telematics link that a component of the vehicle is functioning abnormally and may be in danger of failing.

It is still another object of the present invention to provide a new and improved method and apparatus for obtaining information about a vehicle system and components in the vehicle in conjunction with failure of the component or the vehicle and sending this information to the vehicle manufacturer.

It is an object of the present invention to provide a new and improved method and system for diagnosing components in a vehicle by monitoring the patterns of signals emitted from the vehicle components and, through the use of pattern recognition technology, forecasting component failures before they occur. Vehicle component behavior is thus monitored over time in contrast to systems that wait until a serious condition occurs. The forecast of component failure can be transmitted to a remote location via a telematics link.

It is another object of the present invention to provide a new and improved on-board vehicle diagnostic module utilizing pattern recognition technologies which are trained to differentiate normal from abnormal component behavior. The diagnosis of component behavior can be transmitted to a remote location via a telematics link.

It is yet another object of the present invention to provide a diagnostic module that determines whether a component is operating normally or abnormally based on a time series of data from a single sensor or from multiple sensors that contain a pattern indicative of the operating status of the component. The diagnosis of component operation can be transmitted to a remote location via a telematics link.

It is still another object of the present invention to provide a diagnostic module that determines whether a component is operating normally or abnormally based on data from one or more sensors that are not directly associated with the component, i.e., do not depend on the operation of the component. The diagnosis of component operation can be transmitted to a remote location via a telematics link.

It is an additional object of the present invention to simultaneously monitor several sensors, primarily accelerometers, gyroscopes and strain gages, to determine the state of the vehicle and optionally its occupants and to determine that a vehicle is out of control and possibly headed for an accident, for example. If so, then a signal can be sent to a part of the vehicle control system to attempt to re-establish stability. If this is unsuccessful, then the same system of sensors can monitor the early stages of a crash to make an assessment of the severity of the crash and what occupant protection systems should be deployed and how such occupant protection systems should be deployed.

12

Another object of the invention to provide new and improved sensors for a vehicle which wirelessly transmits information about a state measured or detected by the sensor.

It is another object of the invention to incorporate surface acoustic wave technology into sensors on a vehicle with the data obtained by the sensors being transmittable via a telematics link to a remote location.

It is another object of the invention to provide new and improved sensors for measuring the pressure, temperature and/or acceleration of tires with the data obtained by the sensors being transmittable via a telematics link to a remote location.

It is yet another object of the invention to provide new and improved weight or load measuring sensors, switches, temperature sensors, acceleration sensors, angular position sensors, angular rate sensors, angular acceleration sensors, proximity sensors, rollover sensors, occupant presence and position sensors, strain sensors and humidity sensors which utilize wireless data transmission, wireless power transmission, and/or surface acoustic wave technology with the data obtained by the sensors being transmittable via a telematics link to a remote location.

It is still another object of the present invention to provide new and improved sensors for detecting the presence of fluids or gases which utilize wireless data transmission, wireless power transmission, and/or surface acoustic wave technology with the data obtained by the sensors being transmittable via a telematics link to a remote location.

Yet another object of the present invention to provide new and improved sensors for detecting the condition or friction of a road surface which utilize wireless data transmission, wireless power transmission, and/or surface acoustic wave technology with the data obtained by the sensors being transmittable via a telematics link to a remote location.

Still another object of the present invention to provide new and improved sensors for detecting chemicals which utilize wireless data transmission, wireless power transmission, and/or surface acoustic wave technology with the data obtained by the sensors being transmittable via a telematics link to a remote location.

It is another object of the invention to utilize any of the foregoing sensors for a vehicular component control system in which a component, system or subsystem in the vehicle is controlled based on the information provided by the sensor. Additionally, the information provided by the sensor can be transmitted via a telematics link to one or more remote facilities for further analysis.

A more general object of the invention is to provide new and improved sensors which obtain and provide information about the vehicle, about individual components, systems, vehicle occupants, subsystems, or about the roadway, ambient atmosphere, travel conditions and external objects with the data obtained by the sensors being transmittable via a telematics link to a remote location.

Accordingly to achieve one or more of the above objects, a control system and method for controlling an occupant restraint system in accordance with the invention comprise a plurality of electronic sensors mounted at different locations on the vehicle, each sensor providing a measurement related to a state thereof or a measurement related to a state of the mounting location, and a processor coupled to the sensors and arranged to diagnose the state of the vehicle based on the measurements of the sensors. The processor controls the occupant restraint system based at least in part on the diagnosed state of the vehicle in an attempt to minimize injury to an occupant. Various sensors may be

US 6,850,824 B2

13

used including one or more single axis acceleration sensors, double axis acceleration sensors, triaxial acceleration sensors, high dynamic range accelerometers and gyroscopes such as gyroscopes including a surface acoustic wave resonator which applies standing waves on a piezoelectric substrate. One or more sensors may include an RF response unit in which case, an RF interrogator device causes the RF response unit of to transmit a signal representative of the measurement of the sensor to the processor. A weight sensor may be coupled to a seat in the vehicle for sensing the weight of an occupying item of the seat and to the processor so that the processor controls the occupant restraint system based on the state of the vehicle and the weight of the occupying item of the seat sensed by the weight sensor.

The state of the vehicle diagnosed by the processor includes angular motion of the vehicle, a determination of a location of an impact between the vehicle and another object and/or angular acceleration. In the latter case, several sensors may be accelerometers such that the processor determines the angular acceleration of the vehicle based on the acceleration measured by the accelerometers.

The processor may be designed to forecast the severity of the impact using the force/crush properties of the vehicle at the impact location and control the occupant restraint system based at least in part on the severity of the impact. The processor may also include pattern recognition means for diagnosing the state of the vehicle. A display may be coupled to the processor for displaying an indication of the state of the vehicle. A warning device, alarm or other audible or visible signal indicator may be coupled to the processor for relaying or conveying a warning to an occupant of the vehicle relating to the state of the vehicle. A transmission device may also coupled to the processor for transmitting a signal to a remote site relating to the state of the vehicle.

Another embodiment of a control system for controlling an occupant restraint system comprises a plurality of sensors mounted at different locations on the vehicle, each sensor providing a measurement related to a state thereof or a measurement related to a state of the mounting location and a processor coupled to the sensors and arranged to diagnose the state of the vehicle based on the measurements of the sensors. The processor is arranged to control the occupant restraint system based at least in part on the diagnosed state of the vehicle. At least two of the sensors are a single axis acceleration sensor, a double axis acceleration sensor, a triaxial acceleration sensor or a gyroscope.

The sensors can be used in a control system for controlling a navigation system wherein the state of the vehicle diagnosed by the processor includes angular motion of the vehicle whereby angular position or orientation are derivable from the angular motion. The processor then controls the navigation system based on the angular acceleration of the vehicle.

Principal objects and advantages of this invention or other inventions disclosed herein are thus:

1. To prevent vehicle breakdowns.
2. To alert the driver of the vehicle that a component of the vehicle is functioning differently than normal and might be in danger of failing.
3. To alert the dealer, or other repair facility, that a component of the vehicle is functioning differently than normal and is in danger of failing.
4. To provide an early warning of a potential component failure and to thereby minimize the cost of repairing or replacing the component.
5. To provide a device which will capture available information from signals emanating from vehicle com-

14

ponents for a variety of uses such as current and future vehicle diagnostic purposes.

6. To provide a device that uses information from existing sensors for new purposes thereby increasing the value of existing sensors and, in some cases, eliminating the need for sensors that provide redundant information.
7. To provide a device which is trained to recognize deterioration in the performance of a vehicle component, or of the entire vehicle, based on information in signals emanating from the component or from vehicle angular and linear accelerations.
8. To provide a device which analyzes vibrations from various vehicle components that are transmitted through the vehicle structure and sensed by existing vibration sensors such as vehicular crash sensors used with airbag systems or by special vibration sensors, accelerometers, or gyroscopes.
9. To provide a device which provides information to the vehicle manufacturer of the events leading to a component failure.
10. To apply pattern recognition techniques based on training to diagnosing potential vehicle component failures.
11. To apply component diagnostic techniques in combination with intelligent or smart highways wherein vehicles may be automatically guided without manual control in order to permit the orderly exiting of the vehicle from a restricted roadway prior to a breakdown of the vehicle.
12. To apply trained pattern recognition techniques using multiple sensors to provide an early prediction of the existence and severity of an accident.
13. To utilize pattern recognition techniques and the output from multiple sensors to determine at an early stage that a vehicle rollover might occur and to take corrective action through control of the vehicle acceleration, brakes and steering to prevent the rollover or if it is preventable, to deploy side head protection airbags to reduce the injuries.
14. To use the output from multiple sensors to determine that the vehicle is skidding or sliding and to send messages to the various vehicle control systems to activate the throttle, brakes and/or steering to correct for the vehicle sliding or skidding motion.

Other objects and advantages of the present invention will become apparent from the following description of the preferred embodiments taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The following drawings are illustrative of embodiments of the system developed or adapted using the teachings of this invention and are not meant to limit the scope of the invention as encompassed by the claims.

FIG. 1 is a side view with parts cutaway and removed of a vehicle showing the passenger compartment containing a rear facing child seat on the front passenger seat and a preferred mounting location for an occupant and rear facing child seat presence detector.

FIG. 2 is a side view with parts cutaway and removed showing schematically the interface between the vehicle interior monitoring system of this invention and the vehicle cellular communication system.

FIG. 3 is a diagram of one exemplifying embodiment of the invention.